Malleability of body image: how looking at other people affects perception of our own body

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Originality declaration

I, Klaudia Ambroziak, declare that the work presented in this thesis is my own. Where information has been derived from other people's work or ideas, this is clearly indicated.

The thesis includes research that appears in the following articles:

Chapter 2:

Ambroziak, K. B., Azañón, E., & Longo, M. R. (under review). Body size adaptation produces similar aftereffects for self and others.

Chapter 7:

Ambroziak, K. B., Tamè, L., & Longo, M. R. (2018). Conceptual distortions of hand structure are robust to changes in stimulus information. *Consciousness and Cognition*, 61, 107-116.

Abstract

Visual exposure to very thin or very fat bodies has been shown to influence how people perceive the size and shape of their own body. This thesis aims to contribute to answering the question whether short-term effects of this exposure can constitute an experimental model for the long-term effects of media influences on representation of own body, i.e. body image. First, my results showed no evidence that exposure to other bodies affects perception of one's own body size in a self-specific way. There was, however, an effect on general perception of bodies, e.g. after viewing very thin images, participants judged subsequently presented bodies as fatter than pre-exposure, replicating previous findings. Furthermore, I found similar effects in face perception after exposure to thin faces, which has not been reported before. Moreover, I showed that exposure to individual body parts, i.e. thin or fat faces and hands, can induce analogous changes in perception of entire bodies. I found no effect of visual exposure to another person's hand on perception of tactile distances, suggesting that visual exposure to other bodies does not affect the model of body size underlying the perception of touch on the skin. I showed, however, that haptic exploration of a thin body affects visual perception of bodies, suggesting that body size cues from a different modality can induce changes in visual perception of bodies. Taken together, these results suggest that perceptual biases in body size perception operate on higher-level of processing. In my second line of research, I investigated distal biases in localization of the knuckles on the palm of the hand, showing that such mislocalisations do not rely on any specific sensory modality but rather reflect a conceptual misrepresentation of hand structure. Further, I showed that participants updated their conceptual representation of the hand after visual inspection.

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Chapter 1. General Introduction

1. 1. Introduction

In our daily lives, we constantly experience our own bodies in direct way, e.g. through touch or proprioception. But a great part of our visual experience with bodies comes from looking at other people. For most of us, other people's bodies are a ubiquitous part of our 'visual diet' (Boothroyd, Toveé, & Pollet, 2012). Moreover, through the media we are bombarded with images of other, often idealized, bodies.

In my project, I investigate how visual experience with bodies, especially looking at other people, influences representations of our body. I am particularly interested in the conscious stored representation of our own body which throughout the thesis I will call *the body image*. In the next section of this chapter, I will define the concept of body image in more detail, discuss how it is used in the literature and how it relates to other forms of body representations.

Previous research showed that exposure to thin, idealized images changes attitudes towards one's own body, increases body dissatisfaction and negatively affects mood (Groesz, Levine, & Murnen, 2002; Tiggemann & McGill, 2004). Clearly media can shape our beliefs and attitudes, but can exposure to certain body types change the way we actually *perceive* our own bodies? Recently, several studies suggested that this might be the case and proposed visual adaptation as one of the mechanisms that may be involved in this process (Hummel, Rudolf, Untch, Grabhorn & Mohr, 2012b; Brooks, Mond, Stevenson & Stephen, 2016). In its classic form, visual adaptation produces negative aftereffects which bias perception in the direction opposite to the adapting stimulus. These aftereffects has been demonstrated for both simple features, such as motion (Barlow & Hill, 1963), orientation (Gibson & Radner, 1937), contrast or colour (McCollough, 1965), as well as more complex stimuli such as faces (Rhodes, Jeffery, Watson, Clifford & Nakayama, 2003; Webster, Kaping, Mizokami & Duhamel, 2004)

and bodies (Rhodes, Jeffery, Boeing, & Calder, 2013; Palumbo, Laeng & Tommasi, 2013). It has been demonstrated that adaptation to bodies of a given gender or identity can bias the way we perceive other bodies. Furthermore, previous studies (Winkler & Rhodes, 2005; Glauert, Rhodes, Byrne, Fink & Grammer, 2009) showed that adaptation to extreme body types, i.e. very thin or very fat, can affect what is perceived as the most typical or the most attractive body. Recently, Hummel et al. (2012b) and Brooks et al. (2016) reported that adaptation aftereffect can also bias judgements about one's own body: after adaptation to an image of a thinner version of their own body, participants judged a veridical image of their body to be fatter than before adaptation. These results raise the question of whether some type of natural adaptation to bodies occurs in everyday life, and whether this actually relates to changes in the way we *represent* our bodies. By "representation" I mean the information about a given stimulus/ object (in this case our own body or the sensation of the body) stored in the brain and available even when the stimulus is absent. Perception, on the other hand, is the process that can happen when the stimulus is present. These two are closely connected and affect each other: representations influence perception and perception influence representations.

In this chapter, I will review the literature on both body representations and visual adaptation, and discuss how my work adds to the existing research on this topic.

1. 2. Body representations

1. 2. 1 Types of body representations

Body representations arise from many different sources: interoceptive signals from internal organs, efference copy from the motor cortex, sensory input from the external world coming from modalities such as touch, vision and audition, vestibular and proprioceptive signals but also abstract, conceptual knowledge, beliefs and attitudes (Schwoebel & Coslett, 2005; Longo, Azañón, & Haggard, 2010). With this variety of information the brain forms different types of body representations. The most prominent distinction made in the literature is that between the conscious *body imag*e and the implicit *body schema* (Gallagher & Cole, 1995; Schwoebel & Coslett, 2005; Kammers, Mulder, De Vignemont & Dijkerma, 2009).

Furthermore, researchers distinguish different body schemata which are characterized by different functions, e.g. the *postural schema* represents current posture of the body and its position in space and it is continuously updated, while the *superficial schema* mediates the localisation of touch on the skin (Head and Holmes, 1911; Longo, Azañón, & Haggard, 2010). Other types of body representations include: the *body structural description*, a topological representation mediating knowledge of the spatial layout of bodies, and the *body semantics*, a lexical–semantic representation of the body including body part names and functions (Schwoebel & Coslett, 2005; Corradi-Dell'Acqua, Hesse, Rumiati & Fink, 2008).

My project focuses mainly on the visual aspect of the body image, which I define as a conscious representation of the body as an object in the world and its physical appearance, including its size and shape, as well as the size and shape of the body parts. Visual information is an integral component of body image. In his classic definition, Schilder (1935/1950) used overtly visual language in describing the body image as "the picture of our own body which we form in our mind, that is to say the way in which the body appears to ourselves" (pg. 11). Later in the same text, he adds: "There is always a personality that experiences the perception (…) We have to expect strong emotions concerning our own body". Albeit vague, this definition seems to adequately reflect how the term body image is often used in the literature. The most common usage involves both the mental image ("the picture we form in our mind") as well as the attitudes towards this image. For example, Skrzypek, Wehmeier and Remschmidt (2001) write: "The concept of body image is thought to consist of two components: body size perception and attitudes towards the body". Similarly, Schneider, Frieler, Pfeiffer, Lehmkuhl and Salbach-Andrea (2009) define body image as "a multi-dimensional concept referring to attitudes and perceptions of one's own body". Gallagher and Cole (1995) distinguish three components of body image: "a) the subject's perceptual experience of his/her own body; b) the subject's conceptual understanding (including mythical and/or scientific knowledge) of the body in general; and c) the subject's emotional attitude toward his/her own body".

Body image represents the size of the body and body parts, however, it is not the only source of information about the size and shape of the body. Longo, Azañón and Haggard (2010) describe an implicit model of body size and shape, which is independent from body image and mediates metric properties of tactile stimuli, as well as the position sense (Longo, Azañón, & Haggard, 2010). There are many cases in which the brain uses information about the size of different body parts which is not necessarily explicitly available or accurate. Longo, Azañón and Haggard (2010) distinguished between "cases in which the body is a vehicle for perception, and others in which it is itself the object of perception" (p. 656). The latter cases involves body image, while the former call for the implicit model of body size and shape.

In my project, I focus on the visual aspect of the body image, i.e. a mental picture of the body, although I will also discuss other forms of body representations.

1. 2. 2 Distorted body representations

Outside the realm of science fiction, we cannot escape the body that we inhabit, or, simply put, we are our bodies. Therefore, it is usually assumed that with all the experience we have we know our bodies very well. However, evidence from a great number of studies shows that body representations are often far from accurate. Not only distortions of body representations are present in many clinical disorders but there are also many cases in which similar distortions can be found in healthy participants. In this section, I will review the literature showing various ways in which body representations can be distorted.

Clinical disorders

There are numerous clinical conditions that are characterized by distorted representations of one's own body. Many of them are a result of brain damage following stroke and typically involve delusional beliefs about the side of the body contralateral to the lesion. For example, in somatoparaphrenia patients reject the ownership of their own body part, e.g. limb, and attribute it to someone else (Baier & Karnath, 2008; Vallar & Ronchi, 2009), whereas anosognosia for hemiplegia is characterized by patients' unawareness of their

paralysis and motor deficit (Babinski, 1914; Fotopoulou, Tsakiris, Haggard, Rudd & Kopelman, 2008). These conditions can co-exist and typically involve right brain damage (Baier & Karnath, 2008). Autotopagnosia, on the other hand, is a condition resulting from damage to the left parietal cortex, in which patients are impaired in judgments about the configuration and location of body parts (Buxbaum & Coslett, 2001; Sirigu, Grafman, Bressler, & Sunderland, 1991). Autotopagnosia is generally thought to reflect damage to the body structural description, which mediates knowledge of the spatial layout of bodies (Schwoebel & Coslett, 2005; Corradi-Dell'Acqua et al., 2008; Longo, Azañón, & Haggard, 2010).

Apart from these neurological syndromes with a clear underlying brain lesions, there are several psychiatric disorders which also involve distorted body representations. In the context of my research, the most interesting cases come from disorders linked to distorted body image such as anorexia nervosa and body dysmorphia.

Body dysmorphic disorder (BDD) is characterized by patients' obsessive belief that specific parts of their body (often the face) are strikingly unattractive or even deformed (Marks & Mishan, 1988; Phillips, McElroy, Keck, Pope, & Hudson, 1993). Importantly, other people do not share BDD patients' belief and perceive them as normal looking or even attractive. For example, Marks and Mishan (1988) describe a case study of a male patient who was so convinced that his nose was too large that he covered it with a hand when he spoke to other people or avoided social situations altogether. The authors report that the patient was physically normal. Similarly, Bulchmann, Etcoff and Wilhelm (2008) showed that patients with BDD rated their own faces significantly lower in attractiveness than independent evaluators did. Although many researchers interpret this discrepancy in judgement as a cognitive bias, BDD has also been linked to abnormal visual processing. For example, Clerkin and Teachman (2008) proposed that when BDD patients look in the mirror they do not simply dislike what they see, they literally *see* themselves in a less positive light. Although the attempts to measure this perceptual bias behaviourally showed mixed results (see Beilharz, Castle, Grace and Rossell, 2017 for a review), a recent neuroimaging study by Tan, Shibata,

Philips, Sheinberg, Sasaki and Watanabe (2017) suggests that the neural mechanisms of visual processing and neural plasticity differ between BDD patients and healthy controls.

Another condition traditionally associated with distorted body image is anorexia nervosa (AN). Patients suffering from AN report feeling "fat" and drastically restrict their food intake even though in reality they are often dangerously underweight and malnourished (Bruch, 1962). This misattribution in AN patients describing themselves as "fat" has been interpreted as perceptual body size overestimation. As in case of body dysmorphia, it has been suggested that AN patients not only *judge* themselves as fat but actually *perceive* themselves as fatter than they really are (Slade & Russell, 1973). A number of studies reported that AN patients overestimate their body size (Slade & Russell, 1973; Garner, Garfinkel, Stancer, & Moldofsky, 1976; Thompson, Berland, Linton, & Weinsier, 1986; Smeets, Smit, Panhuysen, & Ingleby, 1997; Farrell, Lee & Shafran, 2005; Schneider, Frieler, Pfeiffer, Lehmkuhl & Salbach-Andrea, 2009). For example, Slade & Russell (1973) asked their participants to estimate the width of various body parts using a moving calliper mounted on a stand. The results showed significant overestimations in the AN patients group but not in the control group. Similar overestimations of the body width were found in studies using a self-adjustable light beam (Thompson et al., 1986) and a distorting photograph technique (Garner et al., 1976). Furthermore, Schneider et al. (2009) investigated body size estimations of the circumference of body parts in adolescents with different types of eating disorders (including AN). Participants used a piece of string to estimate the circumference of their upper arm, their waist and their thigh; specifically, they were asked to place the string on a table and form a circle representing the perceived circumference of the body parts. The results showed that adolescents suffering from AN overestimated their body size by 30%. However, the results of the meta-analysis by Cash and Deagle (1997) based on 66 studies published between 1974 and 1993 suggest that attitudinal body dissatisfaction, assessed by questionnaires and self-ideal discrepancy measures, distinguished AN patients from the controls, whereas perceptual size estimation inaccuracy did not. Similarly, Skrzypek, Wehemeier and Remschmidt (2001) examined the results of 13 studies from 1994-1999 and concluded that these findings "suggest

that body image disturbance is not due to any perceptual deficit, but is based on cognitive-evaluative dissatisfaction". The authors added however that "body size estimation remains a worthwhile approach to assessing body image disturbance in eating disorders" due to its diagnostic and therapeutic implications (p. 215). Mölbert, Thaler, Mohler, Streuber, Romero, Black, Zipfel, Karnath and Giel (2017) also concluded that patients with AN do not suffer from visual distortions but instead have distorted attitudes towards body ideals. Therefore, it remains unclear whether AN patients have distorted visual perception of their body that goes beyond the distortions that can be found in healthy individuals, however, there is consistent evidence that cognitive and affective components of body image in AN patients are disturbed as compared to healthy controls.

It has also been suggested that the feeling of "being fat", typical for AN patients, not only distorts conscious body image but also affects other types of body representations. For example, a study by Guardia, Conversy, Jardri, Lafargue, Thomas, Dodin and Luyat (2012) showed that AN patients have biased judgments about their ability to perform actions such as walking through the door. Participants were presented with a door-like aperture and had to decide whether it was wide enough for them to pass through it without turning to the side. The results showed that AN patients overestimate the width of the aperture necessary in order to perform the action. Importantly, this overestimation was significantly lower when participants were making judgements about another person suggesting that the bias in perceived capacity for action in AN patients is limited to their own body. The authors interpreted their findings as an overestimation of one's own body schema defined as "a dynamic sensorimotor representation of the body which initiates and guides actions". In this view, body schema differs from body image which the authors define as complex and including "perceptual, semantic, aesthetic and emotional representations of the body which are not used for action" (Guardia, Lafargue, Thomas, Dodin, Cottencin & Luyat, 2010). The authors, however, do not sufficiently explain why they think that action initiation and execution is not based on perceptual representation of one's own body that also constitutes body image. Regardless of the answer to this question, the study by Guardia and colleagues (2012) showed a distortion in

sensory body representation that had an effect on participants behaviour which goes beyond aesthetics judgement and attitudes towards one's body.

Healthy population

As I discussed above, distortions of body representations are present in many clinical disorders and there is a vast amount of literature investigating them. Much of this literature implicitly assumes that body representations in healthy population are accurate. However, distortions in a way that bodies are represented has not only been found in patients but also in healthy participants. For example, Thompson and Spana (1988) using the adjustable light beam method found mean overestimation of 21% for the width of three body parts in college age women. Furthermore, while adolescents with eating disorders in the study by Schneider et al. (2009), which I described above, showed an average body overestimation of 30%, healthy control participants in this study overestimated their bodies on average by 8-16% depending on the body part.

Other studies involving healthy population in different types of explicit or implicit tasks also revealed similar distortions. A study by Fuentes, Longo and Haggard (2013) investigated distortions in body image in healthy adults using an implicit measure of body image – a Body Image Task (Fuentes, Pazzaglia, Longo, Scivoletto, & Haggard, 2013) - where participants were shown a single body part (a head) on a monitor as an anchor stimulus and were asked to judge the relative location of several other body parts by clicking on the corresponding location on the screen. The authors found several systematic distortions such as overestimation of the width of the torso relative to the height and underestimation of the relative length of the legs. Linkenauger, Geuss, Stefanucci, Mcculloch, Mohler, & Proffitt (2015) found systematic distortions in the perception of bodily proportions, in a visual estimation tasks, where participants were asked to compare the lengths of two body parts. D'Amour & Harris (2017) reported that people perceive their face as wider and shorter than it actually is as measured by an alternative forced choice task with an adaptive staircase procedure.

Thus, it may be argued that some level of distortion is an inherent property of normal processing of body representations. This seems to go against our intuitions which are so strongly expressed in the language we use. When we want to say that we know something very well, we say we know it “like the back of our hand”. Recent research, however, has revealed that even representations of our hands show systematic distortions. In a study by Longo and Haggard (2010), participants were asked to judge the perceived location of landmarks, i.e. knuckles and fingertips, of their occluded hand. Implicit perceptual maps of hand structure constructed by comparing the relative position of judgments of each landmark, revealed that these maps were highly distorted in a stereotyped way across people, with the hands represented as wider and the fingers as shorter than they actually are (Figure 1.1). Consistent with these results is the finding showing systematic underestimation of the fingers’ length in a task in which participants judged whether different parts of their hand were shorter or longer than a presented line (Longo & Haggard, 2012).

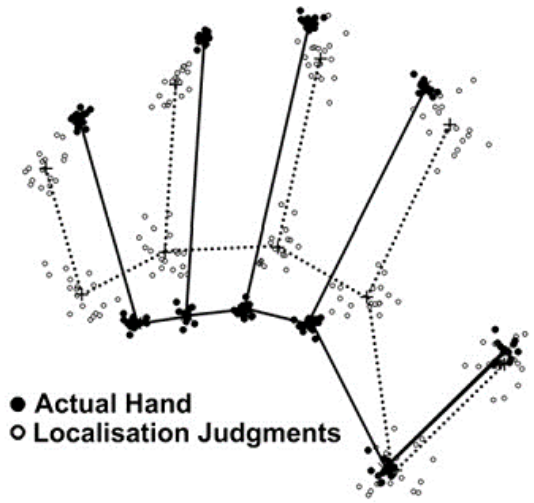

Figure 1.1: Distorted representation of the hand. Longo and Haggard (2010) found that the hand was represented as wider and the fingers as shorter than they actually are. Image source: Longo and Haggard (2010, p. 11729)

Furthermore, Longo and Haggard (2011) showed that when participants judged which of two tactile distances on the hand felt larger, the distances that were aligned with the mediolateral axis (across the hand), were consistently perceived as larger than the distances aligned with the proximodistal axis (along the hand). The same anisotropy effect has been also shown on the forearm (Green, 1982; Le Cornu Knight et al, 2014), thigh (Green, 1982), shin (Stone, Keizer, & Dijkerman, 2018) and face (Longo, Ghosh, & Yahya, 2015; Fiori & Longo, 2018). It is not clear, however, whether distorted maps measured by the proprioceptive localization task are related to the distortions underlying metric properties of perceived touch. Recently, spatial distortions has been shown in localization task for non-corporal objects such as a rake or a CD case (Saulton, Dodds, Bülthoff & de la Rosa, 2015; Saulton, Longo, Bülthoff & de la Rosa, 2016). These distortion were similar but smaller than those found in the hand. However, a study by Saulton, Bülthoff and de la Rosa (2017) demonstrated that after correcting for the conceptual bias of the knuckles location, distortions in hand representations were similar to those present in representations of objects. These results suggested that hand distortions measured in localization tasks (Longo & Haggard, 2010) may be driven by a general misconception about hand landmark locations, i.e. the conceptual bias in the location of the knuckles.

Two recent studies (Longo, 2015; Margolis & Longo, 2015) found that people have highly distorted knowledge of the configuration of landmarks within their hand, specifically their knuckles, i.e., the metacarpophalangeal joints. In the study by Longo (2015), participants used a long baton to indicate the location on the palm directly opposite the knuckle of each finger using the other hand. The results showed that participants consistently judged their knuckles as farther forward in the hand than they actually are, showing a clear distal bias for all fingers aside from the thumb. Furthermore, Margolis and Longo (2015) found similar distal biases when participants were asked to judge the location of their knuckles by clicking the mouse cursor on an empty silhouette, created from an image of the dorsal side of their hand, presented on a screen in front of them. Distal biases were also apparent when participants judged the location of the knuckles of the experimenter's hand (Longo, 2015), suggesting that

the distortion reflects conceptual knowledge about the configuration of hands in general, rather than self-specific representation of one's own hand. These findings show that healthy participants can demonstrate behaviour similar to that observed in clinical disorders such as autotopagnosia which is characterized by distorted conceptual knowledge of the spatial layout of bodies.

Although the evidence suggests that distal bias may be conceptual, the exact origin of the bias are still unknown. Longo (2015) reported similar distal biases when participants localized their knuckles using both touch and vision or only touch (while blindfolded). However, it has not been directly assessed how similar in magnitude the biases is between conditions within a single group of participants and the comparison of visual-tactile and tactile-only judgments was between experiments. Therefore, it remains unclear what kind of sensory information affects these distal biases, and how and to what extent visual and tactile cues might affect them. In Chapter 7, I describe a series of experiments in which I further investigate distal biases in knuckles localization. First, I further investigated whether information from different modalities, i.e. vision and touch, contributes to distal biases and whether these mislocalizations are affected by visual cues such as the crease at the base of the fingers on the palmar hand surface. Next, I investigated whether visual exploration of participant's own hand in movement, i.e. observing the fingers bending, can update the representation of the hand and eliminate distal bias.

Apart from clinical disorders and systematic distortions found in healthy people, there are situations in which body representations can be altered temporarily. In some instances, body representations appear to be rigid, e.g. in the phantom limb syndrome (Ramachandran & Hirstein, 1998). However, there are many cases showing that body representations can be highly malleable and susceptible to changes. For example, cutting off inputs from the peripheral nerves with cutaneous anaesthesia produces the subjective experience that that body part has gotten larger e.g., anaesthesia of the thumb increases the perceived size of the thumb, but also, surprisingly, increases the perceived size of the lips (Gandevia & Phegan, 1999). Other examples of the malleability of body representations come from bodily illusions. The

rubber hand illusion, in which participants receive tactile stimulation to their own, occluded, hand while simultaneously watching a rubber hand being touched in a synchronous way, not only induces a temporarily feeling of ownership over the rubber hand but also affects proprioception (Botvinick & Cohen, 1998). Furthermore, this illusion can be induced as a full-body experience, leading to both a feeling of ownership over a virtual body and a mislocalization of oneself towards the virtual body (Lenggenhager, Tadi, Metzinger & Blanke, 2007). Similarly, watching another person's face being touched synchronously with one's own face leads to the incorporation of a certain percentage of the other person's face into one's own self-identification, the effect known as the enfacement illusion (Tsakiris, 2008). In the Pinocchio illusion (Lackner, 1988), vibration applied to the biceps tendon induces a feeling of elbow extension, which results in an apparent extension of body parts that the hand of the stimulated arm is contacting. For example, participants report a feeling of their nose becoming longer when it is grasped by the hand of the stimulated arm.

In this section, I presented different types of body representations and described various ways in which these representations can be distorted. In my research, I aimed to add to the existing literature by investigating whether visual exposure to other bodies has an effect on body representations, especially body image.

1. 3. Visual adaptation

In my project, to model the effect of media exposure on body image I use visual adaptation. Adaptation in the most broad sense can be defined as an adjustment of the organism to the change in its environment. Clifford and Rhodes (2005) call adaptation "a fundamental property of neurons" (p. 1). In the brain, adaptation occurs on many levels of processing and its time-frame can be measured in seconds, like adjustment to brightness in the retina (Stockman, Langendorfer, Smithson & Sharpe, 2006), minutes, months or even years.

In this section, I will briefly discuss visual adaptation literature, starting with low-level vision research as it forms "the foundations upon which our knowledge of adaptation at higher levels has been built" (Clifford & Rhodes, 2005, p. 2).

1. 3. 1 Adaptation to low-level features

In the classic waterfall illusion, after a short exposure to the flowing water of a waterfall, when the observer looks at a static image, e.g. the rocks beside the waterfall, she will perceive it as moving upwards (Addams, 1834; Barlow & Hill, 1963; Anstis, Verstraten & Mather, 1998). Similarly, adaptation to a left oriented line biases perception of a vertical line to appear as tilted to the right (Gibson & Radner, 1937). These negative aftereffects are the key characteristic of sensory adaptation and have been known since ancient times: the first mention of the motion aftereffects has been credited to Aristotle's *Parva Naturalia* created in the 4th century BC, although it was Lucretius who described its correct, negative direction in his first-century BC poem *De Rerum Natura* (Verstraten, 1996). A vast body of literature has investigated adaptation aftereffects for simple features such as motion (Wohlgemuth, 1911; Barlow & Hill, 1963), orientation (Gibson & Radner, 1937), curvature (Gibson, 1933), contrast and colour (McCollough, 1965), which are thought to be processed mainly at the lower levels of visual hierarchy, with the most classical work dating back to the first half of the twentieth century. Since then, low-level adaptation aftereffects have been well-established and widely studied. While single cell recordings allowed direct measurement of the pattern-selective properties of neurons in the visual cortex of cats and monkeys (Hubel & Wiesel, 1962; Hubel & Wiesel, 1968), adaptation after-effects have been used to infer properties of neurons in humans (Sutherland, 1961; Blakemore & Campbell, 1969; Coltheart, 1971). They have even been referred to as "the psychologist's microelectrode" (Frisby, 1979) for the insight they provide into the processes underlying perception.

There are many theories explaining the neural basis of adaptation. Earlier accounts, dating back to Exner (1894), explained aftereffects in terms of "response fatigue": adaptation to a given feature causes a decrease in the overall firing rate of neurons that code this feature (Sutherland, 1961; Barlow & Hill, 1963; Barlow & Földiák, 1989). However, this explanation has been criticized for a number of reasons (Grill-Spector, Henson & Martin, 2006; Solomon & Kohn, 2014; Vogels, 2016). The most common argument against the response fatigue

hypothesis is that it does not account for the pattern specificity of adaptation (Movshon & Lennie, 1979; Solomon & Kohn, 2014). Furthermore, in some cases adaptation enhances neural responses and not decreases them (Solomon & Kohn, 2014). Alternative explanations of neural adaptation include stimulus-specific changes in the tuning of population responses of neurons (Dragoi, Sharma & Sur, 2000; Jin, Dragoi, Sur & Seung, 2005), normalization (Carandini & Heeger, 2012; Westrick, Heeger & Landy, 2016) and predictive coding (Friston, 2005; Grotheer & Kovács, 2016). According to the first theory, adaptation affects stimulus-specific tuning curves of neurons (Dragoi et al, 2000). It has been shown that neurons in the visual cortex respond selectively to certain features of the stimuli, such as orientation of the line (Hubel & Wiesel, 1962; Hubel & Wiesel, 1968). For example, a neuron may respond strongly to a vertical orientation (it is this neuron's "preferred" orientation). The firing rate of this neuron gradually decreases with stimuli that are tilted further away from vertical orientation reaching the weakest response when presented with a horizontal stimulus. The firing rate of the neuron (or a population of neurons) as a function of stimulus orientation is called a tuning curve. Recent neurophysiological studies have shown that after adaptation to a given orientation the peak of the tuning curve, i.e. the preferred orientation of the neuron, will shift away from the adapting stimulus (Dragoi et al., 2000). If the adapting orientation was close to the preferred orientation of the neuron, the response to what used to be the neuron's preferred orientation will now decrease. Jin et al. (2005) proposed a mathematical model explaining how this shift may be happening at the computational level.

Normalization theory explains adaptation not only through changes in responses of individual neurons but also by accounting for the impact of the neighbouring neurons (Westrick et al., 2016). According to the normalization hypothesis, the responses of individual neurons are divided by the weighted sum of activity of surrounding neurons, the "suppressive field" of the neuron, in order to account for the statistical properties of the entire visual field, i.e. to normalize the responses of the neuron (Carandini & Heeger, 2012). In this framework, adaptation works through constantly updating the normalization weights of the suppressive field i.e. adjusting how much each of the neighbours contributes to the firing rate of the neuron.

Adaptation, therefore, can dynamically strengthen or weaken the connections between pairs of neurons which can result in stronger firing suppression for adapted features.

Although most theories try to explain adaptation through local or "bottom-up" neural mechanisms (starting at early sensory processing stages and propagated to the higher areas), an explanation which involves more global and "top-down" processes has also been proposed, namely predictive coding (Friston, 2005; Auksztulewicz & Friston, 2016). According to the predictive coding hypothesis, at all stages of sensory processing the incoming information is compared with predictions which are generated by higher-level areas based on statistical probabilities (Rao & Ballard, 1999). As a result of this comparison, lower-level areas compute the prediction error and forward it to higher areas, which in turn adjust the predictions. Stimuli which are far from average, and are therefore less probable, result in the biggest prediction errors and evoke the strongest responses. In the predictive coding framework, adaptation changes statistical probabilities of stimuli and consequently the prediction errors which they generate (Grotheer & Kovács, 2016). The hypothesis described here are not all mutually exclusive and it seems possible, or even plausible, that several neural mechanisms contribute to the formation of the adaptation aftereffects.

The neural mechanisms of sensory adaptation remain a matter of debate. However, most recent theories emphasize that, rather than being a biproduct or a sign of fatigue reflecting limitation of the system, adaptation plays an important functional role in vision (Dragoi, Sharma, Miller & Sur, 2002; Clifford & Rhodes, 2005). Although some of the most striking adaptation aftereffects may seem maladaptive, e.g. the motion aftereffect, researchers studying visual adaptation tend to see adaptation as a crucial tool recalibrating the sensory system to the environment (Clifford & Rhodes, 2005). There is a great number of neurons in the visual cortex but that number is fixed, whereas the potential range of stimuli in the environment is unlimited. Thus, one of the main purposes of adaptation is to recalibrate the mapping between sensory input and neural responses to encode stimuli in the most efficient way (Clifford & Rhodes, 2005). Adaptation allows the sensory system to remove the redundant signal so a wider range of stimuli can be represented using only a limited set of neurons. The most basic

example is light adaptation which constantly resets the sensitivity of neurons in the retina to match the brightness level of the visual field (Malchow & Yazulla, 1986; Rodieck, 1998; Stockman et al., 2006). Without that process, a great number of neurons would be saturated most of the time. In case of motion adaptation, accurate perception of absolute speed is sacrificed in order to increase differential speed sensitivity: when moving with constant speed, it is more efficient to reduce the steady firing rate and use the whole dynamic range to detect speed change (Clifford & Langley, 1996; Ibbotson, 2005).

These examples show that adaptation in the visual system can recalibrate its responses to the statistical regularities of its input. This context sensitive calibration occurs at different levels of visual processing: brightness adaptation occurs in the retina (Shapley & Enroth-Cugell, 1984; Malchow & Yazulla, 1986), adaptation to orientation and motion happens in the cortex, in primary visual area V1 (Patterson, Wissing & Kohn, 2013; Kohn & Movshon, 2003; Morgan, Schreiber & Solomon, 2016). However, growing evidence suggests that changes in neural responses induced by adaptation are not limited to early visual areas but can also be found in the middle temporal area MT (Kar & Krekelberg, 2016) and in inferior temporal cortex (Vogels, 2016) which are the end-stages of visual pathways, raising the question of whether the mechanisms of adaptation affect visual representations at all stages of processing.

1. 3. 2 High-level aftereffects

Low-level aftereffects show that adaptation is ubiquitous in the human visual system, allowing recalibration to the statistical regularities of its input. Recent evidence suggests that not only low-level perception gets recalibrated but that context sensitive calibration occurs at different levels of representations. For example, Green and Oliva (2010) showed that adaptation can bias categorization of global scene properties: adaptation to urban landscapes affected whether a test scene was perceived as more natural or manmade. Importantly, these aftereffects were preserved when the adapting and test images were presented at different retinotopic locations, suggesting that the origin of these aftereffects is not solely due to low-level adaptation.

A growing number of studies report negative aftereffects for complex stimuli such as faces, bodies or even actions (Webster, Kaping, Mizokami & Duhamel, 2004; Winkler & Rhodes, 2005; Barraclough & Jellema, 2011). Research on face adaptation shows that adaptation to a specific feature of a face causes other faces to appear biased in the opposite direction, e.g. exposure to a male face causes neutral faces to appear more feminine and vice versa (Webster et al., 2004, see Figure 1.2, top row).

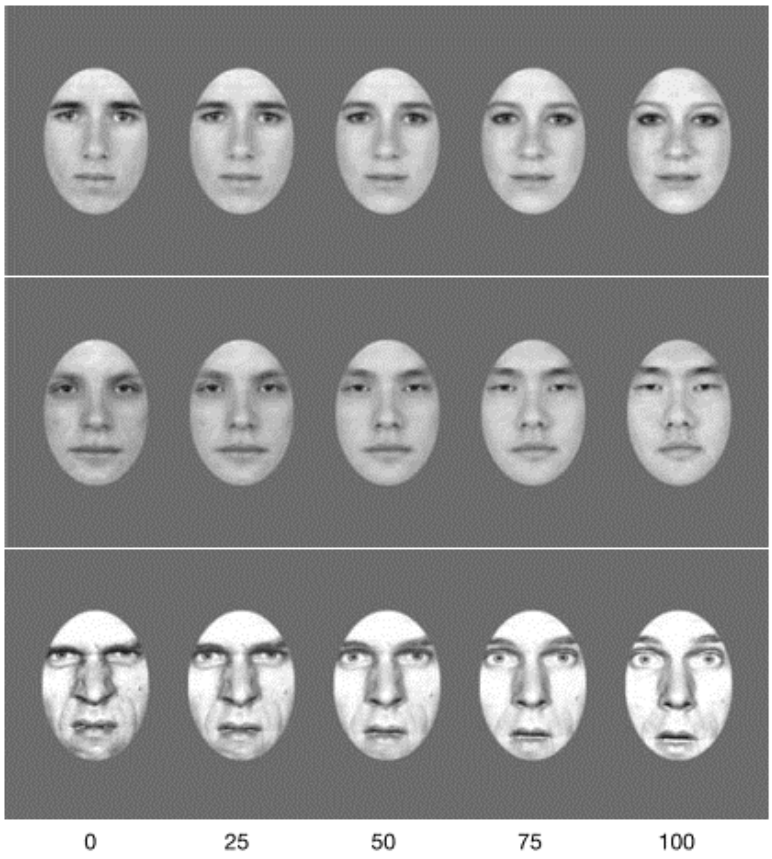

Figure 1.2: Face adaptation. Examples of the stimuli used in the study by Webster et al. (2004) for the dimensions of gender (top row), ethnicity (middle row), or expression (bottom row). Adaptation to one of the extreme images (0/100) biases the perception of the neutral image (50) in the direction opposite to the adaptor. Image source: Webster et al. (2004, p. 558)

These negative aftereffects were reported for features such as gender (Webster et al., 2004), identity (Leopold, O'Toole, Vetter & Blanz, 2001), ethnicity (Webster et al., 2004), emotional expression (Webster et al., 2004), age (Schweinberger, Zäske, Walther, Golle, Kovács and Wiese, 2010), and gaze direction (Calder, Jenkins, Cassel & Clifford, 2008). Furthermore, adaptation to faces with consistent distortions, i.e., compressing or expanding the centre of a face, causes normal faces to appear distorted in the opposite direction (Webster & MacLin, 1999; Rhodes, Jeffery, Watson, Clifford, & Nakayama, 2003; Watson & Clifford, 2003).

Similarly, adaptation to a specific body type or feature, can affect perception of subsequently presented bodies, e.g. adaptation to a female body causes androgynous bodies to appear more masculine (Palumbo, Laeng & Tommasi, 2013). A growing number of studies have investigated adaptation to bodies with a focus on body size (Winkler & Rhodes, 2005; Glauert, Rhodes, Byrne, Fink, & Grammer, 2009; Hummel, Grabhorn & Mohr, 2012a; Hummel, Rudolf, Untch, Grabhorn & Mohr, 2012b; Brooks, Mond, Stevenson & Stephen, 2016). It has been shown that exposure to extreme body types (very thin or very fat) affects perceived adiposity of other bodies i.e., exposure to a thin bodies makes subsequently presented bodies appear fatter and vice versa.

Adaptation can also bias perceived action (Barraclough & Jellema, 2011; de la Rosa, Streuber, Giese, Bülthoff & Curio, 2014; de la Rosa, Ekramnia, & Bülthoff, 2016; de la Rosa, Ferstl, Bülthoff, 2016; Fedorov, Chang, Giese, Bülthoff, & de la Rosa, 2018). Barraclough & Jellema (2011) found that after watching a short videoclip of an actor walking forwards, participants perceived subsequently presented pairs of static images as showing the actor walking backwards. The action was presented on a unified background to eliminate cues that were not directly related to the movement of the actor. Furthermore, several studies has shown that adaptation to an action biases perception of an ambiguous action containing elements of two actions away from the adapting stimulus, e.g. after adaptation to a "throwing" action, participants perceived a "giving-throwing" morph as a "giving" action (de la Rosa, Streuber, Giese, Bülthoff & Curio, 2014; de la Rosa, Ferstl, Bülthoff, 2016). Interestingly, Fedorov et

al. (2018) found similar bias in throwing-giving perception after adaptation to catching, suggesting that representations of contingent actions (e.g. giving and taking, throwing and catching) are linked together by selective encoding mechanisms.

The examples of high-level aftereffects get increasingly more abstract: it has also been shown that adaptation aftereffects transfer between stimuli belonging to different categories, e.g. bodies and faces (Ghuman, McDaniel and Martin, 2010; Palumbo, D'Ascenzo and Tommasi, 2015) or even different modalities, e.g. Matsumiya (2013) showed that emotional-expression aftereffects transfer from touch to vision. However, the nature of higher-level adaptation evokes some controversies with researchers debating whether these high-level aftereffects are really perceptual (Storrs, 2015). I will further discuss this issue in Chapter 6 and 8.

1. 4. Adaptation as a model of media influences on body image

In previous sections, I defined body image as a conscious representation of the size and shape of the body and the attitudes towards it. As such, the concept of body image includes the amount of satisfaction people feel about their appearance. Further, this satisfaction seems to be decreasing in modern societies to the point that it is now considered to be a prevalent problem by many researchers (Grogan, 2017; Neighbors & Sobal, 2007). In this chapter, I already discussed eating disorders such as anorexia nervosa, which are now on the rise: in the UK number of people looking for professional help has systematically increased by 34% from 2005 to 2015 (Beat: beating eating disorders, 2015). However, body image dissatisfaction is clearly not limited to clinical populations. The All Party Parliamentary Group on Body Image (2012) estimates that two thirds of adults suffer from negative body image. Body dissatisfaction seems to start with young age: 34% of adolescent boys and 49% of girls have been on a diet to change their body shape or to lose weight (The All Party Parliamentary Group on Body Image, 2012). Media are often blamed for creating unrealistic, unhealthy body ideals (Grogan, 2007; Derenne & Beresin, 2006). It has been shown that exposure to thin, idealized images changes attitudes towards one's own body, increases body dissatisfaction and

negatively affects mood (Groesz, Levine, & Murnen, 2002; Tiggemann & McGill, 2004). There is clear evidence that media can shape our beliefs and attitudes but the question that remains is whether media can also influence the way we actually *perceive* ourselves. Recently, it has been suggested that indeed exposure to extreme body types can influence the way we actually *see* our own bodies (Hummel, Rudolf, Untch, Grabhorn & Mohr, 2012b; Brooks, Mond, Stevenson & Stephen, 2016; Challinor, Mond, Stephen, Mitchison, Hay & Brooks 2017).

In this project, I was interested whether visual adaptation may be one of the mechanisms affecting the perceptual component of body image. Studies by Winkler and Rhodes (2005) and Glauert et al. (2009) showed that adaptation to extreme body types can affect what is perceived as the most typical or most attractive body. After exposure to very thin bodies, observers judge the same test bodies to be less attractive than pre-exposure. In consequence, the body previously perceived as most "average" after adaptation seemed fatter, and the image that now appeared most typical - the new norm - was shifted towards the thin adaptor. Similarly, the body perceived as the most attractive after adaptation was thinner than the body judged as most attractive before the adaptation.

Moreover, research by Hummel et al. (2012b) showed that adaptation to fat or thin bodies altered the way subjects judged images of their own bodies. In this study, pictures of participants own bodies were manipulated to create a whole range of images of bodies that were fatter and thinner than the original. In one experiment, participants were adapted to a thinner or a fatter version of their own body (Figure 1.3) and then asked whether test images from the whole range of manipulated images were thinner or fatter than their own body. In another experiment, during the exposure participants were shown fat or thin bodies of other people. In both experiments, adaptation to thin stimuli (thinner versions of participant's body or thin bodies of others) caused the actual picture of participant's body to appear fatter. Consequently, participants chose the thinner image of themselves to be the most realistic.

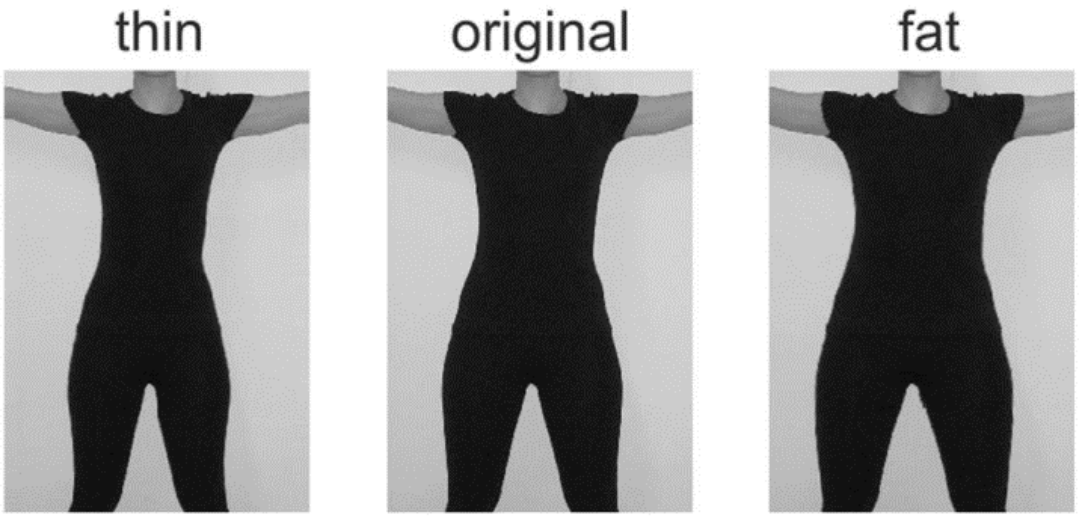

Figure 1.3: Adaptation to participants' bodies. Examples of the stimuli in the study by Hummel et al. (2012b). The images of participants' bodies were manipulated to create images of bodies that were fatter and thinner than the original. Image source: Hummel et al. (2012b, p. 3)

Importantly, Hummel, Grabhorn and Mohr (2012a) showed that adaptation to narrow/wide rectangles did not produce similar aftereffects suggesting that this effect is specific to bodies. The authors suggests that their results reflect a perceptual bias similar to those evoked by exposure to thin ideals in Western culture and that this bias may contribute to the development of body image disorders. Similarly, Brooks et al. (2016) argued that visual adaptation may constitute a model of real-life exposure to thin ideals and its effect on body image distortions. Their study showed transfer between two identities, using a single adapting stimulus (participant's or other person's body) but two different test stimuli (participant and other). The effect of adaptation on the test stimuli that differed from the adaptor was significant, though smaller than the effect between the stimuli of the same identity.

The results of these studies raise the question of whether some natural adaptation to body size occurs in everyday life, and whether it relates to changes in body representations. Thus, the main subjects of my thesis deals with the question whether short-term effects of adaptation can constitute an experimental model for the long-term effects of media influences on body image.

Previous studies provide evidence that adaptation to extreme body types affects perception of bodies. The question nevertheless remains how similar the effects of adaptation are for one's own body and bodies of others. As noted by Brooks et al. (2016), for visual adaptation to constitute an experimental model of media effect on body image distortions, some overlap in the way adaptation affects one's own body and bodies of others is required to allow the transfer of aftereffects from media images to body image. I agree with this view, especially considering that it is plausible that neural representations of own body and other bodies are related as they share most features. I believe that we construct the image of our own body in reference to the other bodies that we see and these representations are always in relation to each other. However, I also believe that the effect that adaptation has on one's own body should also be allowed to differ from the general effect of adaptation on all images of bodies. If visual adaptation has no self-specific component, it may be a poor candidate for explaining body image distortions characterized by distorted perception of own body, since adaptation which biases all body representations equally, should not affect the relative difference between one's own body and other bodies. In that case, the effect of adaptation would not be noticeable by the observer herself and thus unlikely to affect her attitudes towards her body. To investigate whether exposure to bodies affects judgements about our own body in a self-specific way, or the effect is generic to all bodies, I designed a series of adaptation experiments which I discuss in Chapter 2.

The task used in most body adaptation studies involves comparing a visual stimulus of a body to a stored representation of one's own body (i.e., the body image). There are two ways in which adaptation can affect body size judgments: (1) it might alter stored representations of participant's body, or (2) it can alter the way participants perceive the visual test stimuli without affecting stored representations. It remains unclear whether adaptation affects stored body representations or only the immediately presented visual image. In Chapter 3, I attempted to answer the question using the Body Image Task (Fuentes et al. 2013) in which participants judged the location of their own body parts relative to an anchor (a head) which

allows to construe implicit maps of participants' perceived body size and shape. Critically, no visual stimulus of a body is presented during the test phase.

Another way of testing whether the effect of adaptation goes beyond changes in visual perception is to look whether it affects body representations in other modalities. Previous research show that representations of the body underlie tactile size perception: modifying the perceived size of body parts produces corresponding changes in the perceived size of objects touching the skin (Taylor-Clarke, Jacobsen & Haggard, 2004). In Chapter 6, I investigated whether adaptation to body size can transfer between vision and touch.

Adaptation studies use images of whole bodies as adaptors, which is not always how we perceive bodies in the real world. In our daily life, both in our environment and in media, we often see bodies that are only partially visible and partially occluded, e.g. people sitting behind desks, profile pictures in social media and partial body photographs in magazines. Thus, another interesting question is whether exposure to a whole body is necessary for adaptation to occur. In my project, I was interested whether images of body parts can induce body size adaptation. I conducted a series of experiments which tested whether adaptation to extreme body types can transfer between whole bodies and body parts such as faces and hands. I discuss the results in Chapter 5.

Previous research showed that women are more concerned with their weight and body image as compared to men and more often perceive themselves as overweight even if in reality they are not (Tiggemann & Rothblum, 1988; Muth & Cash, 1997). Therefore, the majority of previous body size adaptation literature focused exclusively on women (e.g. Glauert at al., 2009; Hummel et al., 2012, Brooks et al., 2016). In all experiments presented in Chapters 2-6, I also restricted my samples to female participants. I decided to do this as I was addressing a new question within body adaptation research and I wanted to make it possible to interpret my results in the light of previous findings and avoid potential issues of whether inconsistent results could be caused by testing different population.

1. 5. Organization of the thesis

The aim of this thesis is to contribute to knowledge of how visual exposure to other bodies affects body representations. In the next chapters, I describe the research I conducted during my doctoral studies. The main topic of my investigations was the effect of visual adaptation to extreme bodies on body image. I discussed the main motivation for my work in the previous sections. Here, I summarize the organization of the thesis in terms of the content of each chapter.

In Chapter 2, I discuss three experiments investigating whether visual exposure to extreme body types affects judgements about one's own body and other bodies in a similar way. I used a visual adaptation paradigm with very thin or fat bodies as adaptors and a range of bodies of different sizes as test stimuli. Participants were adapted to pictures of thin or fat bodies and then rated whether test bodies were fatter or thinner than either: their own body (Experiments 1-3), an average body (Experiment 1) or the body of another person (Experiments 2-3). My results replicate previous findings showing that visual adaptation to extreme body types affects body size judgments of one's own body (Hummel et al., 2012b; Brooks et al., 2016) Critically, however, I found virtually identical effects for judgments of other people's bodies. This suggests that adaption does not have specific effects on the participant's body image. One possible interpretation of these results is that visual adaptation affects visual perception of immediately perceived visual stimuli but not stored representations.

I follow up on this question in a study described in Chapter 3, which further investigates whether adaptation affects stored representation of one's body using an implicit Body Image Task (BIT, Fuentes et al., 2013). In the BIT, participants judge the location of their own body parts relative to an anchor (a head) which allows construction of implicit maps of participants' perceived body size and shape. Here, participants performed the task before and after adaptation to a very thin body. I found no effect of adaptation on the implicit maps that emerged from BIT suggesting that adaptation does not affect stored body image. This interpretation is consistent with the findings described in Chapter 2.

In Chapter 4, I present an experiment testing adiposity adaptation in faces. My results showed for the first time that exposure to facial adiposity of the adaptor produces negative aftereffects in perception of subsequently presented faces, similar to those reported in body adaptation studies (Winkler and Rhodes, 2005; Glauert et al., 2009). The results of this experiment also serve as a preliminary finding for my investigations of cross-category transfer which I describe in Chapter 5.

Chapter 5 reports a series of experiments studying cross-category transfer of adiposity aftereffects between the whole bodies and body parts, i.e. faces and hands. I used the same adaptation paradigm as in Chapter 2 but with faces and hands as adaptors and bodies as test stimuli (Experiment 1, 2 and 4) or with bodies as adaptors and faces as test stimuli (Experiment 3). I found that exposure to body parts can induce body size aftereffects in perception of a whole body and vice versa. These results show that partial images of bodies can serve as adiposity cues and induce body size adaptation. These findings are consistent with previous studies reporting cross category adaptation to features such as gender and identity (Ghuman, McDaniel and Martin, 2010; Palumbo, D'Ascenzo and Tommasi, 2015) and suggest that adaptation may operate on higher-levels of visual representations.

In studies described in Chapter 6, I explored cross-modal adaptation to body size. In two experiments, I tested whether body size aftereffects transfer between different modalities, i.e. vision and passive touch (Experiment 1) and between haptics and vision (Experiment 2). In Experiment 1, I made use of an effect known as tactile anisotropy (Longo & Haggard, 2011) to test whether visual adaptation affects perceived tactile distance on the hand. I found similar anisotropy before and after adaptation suggesting that visual adaptation did not affect the model of body size underlying tactile perception. In Experiment 2, I used a similar adaptation paradigm as in Chapter 2, 4 and 5 but with three-dimensional figures as adaptors. During adaptation, participants haptically explored the figures and then made judgements about the visual test stimuli. I found some evidence of cross-modal transfer of body size aftereffects in the thin but not in the fat condition.

In Chapter 7, I discuss a series of experiments investigating mislocalizations of the knuckles of the hand following up on Longo (2015) who found that people systematically judge their knuckles to be farther forward in the hand than they actually are, showing a clear distal bias. The cause of this effect, however, remains unclear. To investigate what information affects distal bias I conducted four experiments. First, I tested whether distal bias depends on a particular modality, using a task that involved either vision alone, touch alone or both vision and touch. I found clear mislocalisations in all conditions. Then, I asked whether landmarks such as crease affect distal bias. Participants localized their knuckles on either a photograph of their palm or a silhouette. Distal mislocalisations were apparent in both conditions. These results show that distal biases are resistant to changes in stimulus information, suggesting that such mislocalisations reflect a conceptual mis-representation of hand structure. Finally in Experiment 3 and 4, I asked whether careful, visual inspection of one's own hand in movement i.e. observing the fingers bending, can update the representation of the hand and eliminate distal bias. I found that visual inspection reduced but not eliminated the bias.

Finally, I summarise all my findings in Chapter 8. I discuss whether body size adaptation aftereffects can be explained either by adaptation to low-level features or as a conceptual bias and I conclude that the most likely explanation is that the aftereffects reflect changes to representations in higher level visual areas. I discuss possible underlying mechanisms of body adaptation. I also discuss the limitations of my studies and possible directions for future research.

Chapter 2: Body size adaptation aftereffects for self and others

2. 1. Introduction

The main topic of my thesis is the effect of visual exposure to extreme bodies on body representations. In this chapter, I will discuss three experiments investigating whether adaptation to extreme body types affects judgements about one's own body and other bodies in a similar way.

Research on body adaptation has shown that brief exposure to unfamiliar thin bodies, significantly alters people's perception of body attractiveness, normality, and ideals, in the direction of the thin adaptor (Winkler & Rhodes, 2005; Glauert, Rhodes, Byrne, Fink, & Grammer, 2009). Moreover, adaptation to participants' own bodies, depicting them as either thinner or fatter, can also alter the way participants judge images of their own bodies. After adaptation to the thin version of their own body, participants rated a thinner than actual image to be the most accurate depiction of their own body and vice versa for the fat adaptor (Hummel et al., 2012a, 2012b, 2013). Interestingly, the effect of body adaptation transfers across identities, with comparable effects for unfamiliar and own body adaptors (Hummel et al., 2012b). Moreover, it is specific to bodies, and does not transfer between bodies and narrow/wide rectangles (Hummel et al. (2012a). Taken together, these findings show that exposure to thin images not only affects perceived norms and ideals (Winkler & Rhodes 2005; Glauert et al., 2009) but can also change how participants judge images of their own body – causing the actual image of the participant's body to appear fatter (Hummel et al., 2012 b; Brooks et al., 2016). These results suggest that visual adaptation may serve as an experimental model of the effect that exposure to thin bodies presented in media has on body image. Following this line of reasoning, Challinor, Mond, Stephen, Mitchison, Stevenson, Hay & Brooks (2017) proposed that including visual adaptation as a part of treatment may have therapeutic effect on patients with body image distortions in conditions such as anorexia nervosa.

There is clear evidence that body size adaptation affects perception of bodies. The question nevertheless remains how similar the effects of adaptation are for one's own body (i.e., the body image) and for bodies in general. Specifically, it is not known whether exposure to bodies affects judgements about our own body in a self-specific way, or if the effect is generic to all bodies. For visual adaptation to constitute an experimental model of media effect on body image distortions, some overlap in the way adaptation affects one's own body and bodies of others is required to allow the transfer of aftereffects from media images to body image. However, the effect that adaptation has on one's own body should also differ from the general effect of adaptation on all images of bodies. If adaptation affects all bodies equally, the relative difference between one's own body and other bodies should not change. In other words, the perception of both our own bodies and bodies presented in media should be affected by adaptation. In consequence, our own body should not appear to us as fatter in the whole continuum of bodies, i.e., if we were to compare our body to other bodies.

To investigate whether visual exposure to extreme body types affects the perception of our own body and of other bodies in similar or different ways, I designed three experiments in which female participants judged the same images but making different judgments. After adaptation to pictures of either extremely thin or extremely fat bodies, participants were asked to rate whether subsequently presented bodies were fatter or thinner than either: their own body (all three experiments), the average body (Experiment 1) or a body of a specific other person (Experiment 2 and 3). What makes something a body image judgement is the fact that the reference (a photograph, a silhouette or even a piece of string) is compared to one's own body and not the nature of the reference itself. By keeping the visual stimuli constant but changing the task/type of judgement, I investigated how adaptation affects different stored representations of bodies i.e. own body image vs representations of others. Interestingly, a previous study by de la Rosa, Streuber, Giese, Bulthoff and Curio (2014) reported modulation of action adaptation aftereffects across two conditions which had identical adapting and test stimuli but differed with respect to the information that was provided prior to the adaptation, i.e. the social context, suggesting that the context of the task can affect adaptation aftereffects.

Body image tasks such as those used in previous studies of body size adaptation aftereffects (Hummel et al., 2012 b; Brooks et al., 2016) involve comparing a visual stimulus of a body to a stored representation of one's own body (i.e., the body image). There are two ways in which adaptation might affect body size image judgments: (1) it might alter participants' stored body image, or (2) it can alter the way participants perceive *the visual test stimuli* without affecting stored representations. If the latter is true, adaptation would affect body image *judgments*, without altering the body image itself. If adaptation aftereffects affect judgments of other bodies in the same way as judgments of one's own body, it would suggest that the latter effect is driven by changes in how the viewer perceives the test stimulus, rather than in changes to the body image itself. If, however, adaptation affects stored body representations, it could be possible that it affects self and other bodies differently. There are many clinical conditions in which people have distorted image of their own body, but not other people's (whereas the opposite is very rare). For example, previous studies suggested that patients with anorexia nervosa have a distorted representation of their own body but not a perceptual distortion of all bodies. In a study by Guardia, Conversy, Jardri, Lafargue, Thomas, Dodin and Luyat (2012) patients showed biased judgments about their own actions but could accurately judge the affordances of others. These results suggest that anorexia nervosa patients do not have distorted representations of other people's bodies.

If visual adaptation affects representations of self and others equally, it is a poor candidate for explaining body image distortions and eating disorders. Thus, for adaptation to constitute a model of media on distorted body image, it seems necessary that it has some self-specific component, i.e. induce changes that are partially specific to the representation of one's own body.

2. 2. Experiment 1

In Experiment 1, I investigated the effect of visual adaptation to thin bodies on judgments of one's own body and of an average body. The effect of adaptation on both perceived averageness (Winkler & Rhodes, 2005; Glauert et al., 2009) and perception of one's

own body have been previously demonstrated (Hummel et al., 2012 b; Brooks et al., 2016). However the size of the aftereffects has never been compared in the same group of participants. If adaptation has a specific effect on body image, the magnitude of adaptation aftereffects should differ depending on whether participants are judging their own body or somebody else's. If, in contrast, adaptation affects body image judgments by altering perception of the test stimuli, identical aftereffects should be found in both cases.

2. 2. 1. Methods

Participants

Due to the reasons discussed in the introduction, I restricted my sample to female participants. A different group of participants was selected in each study. Twenty participants (mean age: 28.1, SD: 11.6, range: 18 - 65; mean body mass index, BMI: 21.9, SD: 3.1, range 17.9 – 29.1) took part in Experiment 1. All participants had normal or corrected to normal vision. All participants gave informed consent and were paid for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London. Previous studies showed that adaptation to bodies produces strong and robust effects. For example Hummel et al. (2012b) using similar stimuli and judgments in two experiments obtained Cohen's d_z's of 2.87 and 1.04. I conducted a power analysis using G*Power 3.1 taking the smaller of these two effect sizes, an alpha value of 0.05 and power of 0.95, which indicated that 12 participants were required. In addition, piloting data using my paradigm showed adaptation effects in virtually every participant. Thus, I believe that the sample size of 20 participants makes this experiment well-powered to address this issue.

Stimuli

I used a set of 89 images of female bodies rendered from 3-D avatars, that I generated in DAZ Studio 4.8 (DAZ Productions, http://www.daz3d.com/). Avatars' BMI ranged from

13 (emaciated) to 35 (obese) with an increment of 0.25 BMI units between each stimulus (with a total of 89 images; see Figure 2.1 for examples). To create biologically realistic avatars with veridical BMI changes, I followed a paper by Cornelissen et al. (2009). Using data from the Health Survey for England (Health Survey for England, 2003), Cornelissen and colleagues derived a formula to calculate the waist to hip ratio (WHR) for white UK women of reproductive age:

$$WHR = (2.057*BMI + 29.67) / (1.842*BMI+56.004)$$

Following this formula, I estimated waist and hip circumferences separately for each required BMI from the range of 13 to 35. Next, I adjusted waist and hip circumferences of all my avatars using the Universal Sizing Apparatus tool (Rocketship Technologies Inc., http://rocketship3d.com/).

The height of the avatars was kept constant at 170 cm. The avatars were rotated approximately 45° around the vertical axis (in the transverse plane) to obtain a viewing angle that would provide more information about the body dimensions compared to the straight-facing view. Finally, I rendered 2D images from the avatars, as shown in Figure 2.1.

Figure 2.1: Stimuli used in the experiments. A continuum of 89 body shapes was created, ranging from extremely thin (i.e., BMI = 13) to obese (i.e., BMI = 35). 3-D modelling software was used to model these changes in a biologically-realistic way. The numbers indicate the estimated body mass index (BMI) of the avatars.

Procedures

Each experiment consisted of the *Baseline* and the *Adaptation* phase. In Experiments 1 and 2 a very thin body (BMI=13) was used as an adapting stimulus. In Experiment 3, the procedure was repeated twice, using both a very thin (BMI=13) and a very fat adaptor (BMI=35). In all experiments participants sat approximately 50 cm from the screen with head movements unrestricted. Images were presented in the centre of a 24 inch screen, on a black background. Stereoscopic depth was not used. The height of each image was 18 cm (20° visual angle). Stimuli were presented using Psychtoolbox (Brainard, 1997), running on MATLAB (Mathworks, Natick, MA). The thresholds were calculated using a Bayesian adaptive algorithm QUEST (Watson & Pelli, 1983). Statistical analyses were performed in JASP (JASP Team, 2017).

In the Baseline phase, each trial began with a blank screen (1000 ms), followed by a fixation cross (1000 ms) that turned from black to red to indicate the beginning of a new trial. Then, a question appeared on the screen: *Is this body fatter than your own?* in the *Self* condition, or *Is this body fatter than average?* in the *Average* condition. Before the start of the task, I explained to participants that "average" means the most common/typical body for their age and gender (according to their best guess). The question was followed by a 1000 ms test body selected by QUEST, from a set of possible stimuli based on their history of responses on previous trials. A blank screen remained visible until the response was made using labelled keyboard keys ("yes"/"no"). After the response, a black cross appeared on the screen for 1000 ms indicating the end of the trial. Each part was divided in four blocks of 40 trials (2 blocks per condition, ABBA order counterbalanced across participants). At the end of each block, the point of subjective equality (PSE, i.e., the stimulus for which the participant was equally likely to judge it as fatter or thinner) was calculated using QUEST. Then, I averaged the PSEs from the two blocks to obtain a single estimate for each condition, separately for the Baseline and the Adaptation phase.

The Adaptation phase started with an initial 2 min exposure to the thin adaptor. The adaptor flickered every 4 seconds (disappearing for 500 ms and appearing again) to maintain

attention. After that, participants performed the same task as in the Baseline phase. Each trial in the Adaptation phase was identical to the Baseline with the addition of a thin body exposure. A very thin adaptor (BMI 13) was presented for 8 seconds to 'top-up' the adaptation, followed by one second of blank screen, just before the presentation of the corresponding question (i.e., *is this body fatter than your own / average*) and the test stimulus. Again, the PSE was calculated after every block, resulting in 2 thresholds per condition.

2. 2. 2. Results

In each experimental session, two 50% thresholds (PSEs) per condition were calculated using QUEST to estimate the BMI at which participants were equally likely to respond thinner or fatter. These two thresholds were then averaged, resulting in 4 PSEs, one for each condition (*Self*, *Average*) and adaptation phase (*Baseline* and *Adaptation*). The results are shown in Figure 2.2 (left panel). Clear adaptation aftereffects were apparent in both conditions. There was a clear decrease in perceived BMI from *Baseline* to *Adaptation*, both in the *Self* condition (mean change: 2.22, SD: 1.24), $t(19) = 8.05$, $p < 0.001$, $d_z = 1.80$, and in the *Average* condition (mean change: 2.26, SD: 1.68), $t(19) = 6.00$, $p < 0.001$, $d_z = 1.34$.

To investigate the effects of the two judgment types, I conducted a 2x2 repeated measures analysis of variance (ANOVA) on the PSEs with factors *condition* (*Self* / *Average*) and *adaptation* (*Baseline* / *Adaptation*). I found a main effect of adaptation, $F(1, 19) = 50.78$, $p < 0.001$, $\eta_p^2 = 0.75$. That is, after adaptation to a thin adaptor, participants perceived as fatter, images that before adaptation were considered as thinner (see Figure 2.2). There was no effect of condition, $F(1, 19) = 0.74$, $p = 0.4$, $\eta_p^2 = 0.04$, suggesting that on average participants did not judge themselves as fatter or thinner than a typical woman. Critically, there was no interaction, $F(1, 19) = 0.026$, $p = 0.874$, $\eta_p^2 = 0.00$, suggesting that adaptation affected participants' perception of themselves in the same way it affected perception of typicality. Moreover, the magnitude of the aftereffects in both conditions was correlated across participants, $r = 0.85$, $p < 0.001$.

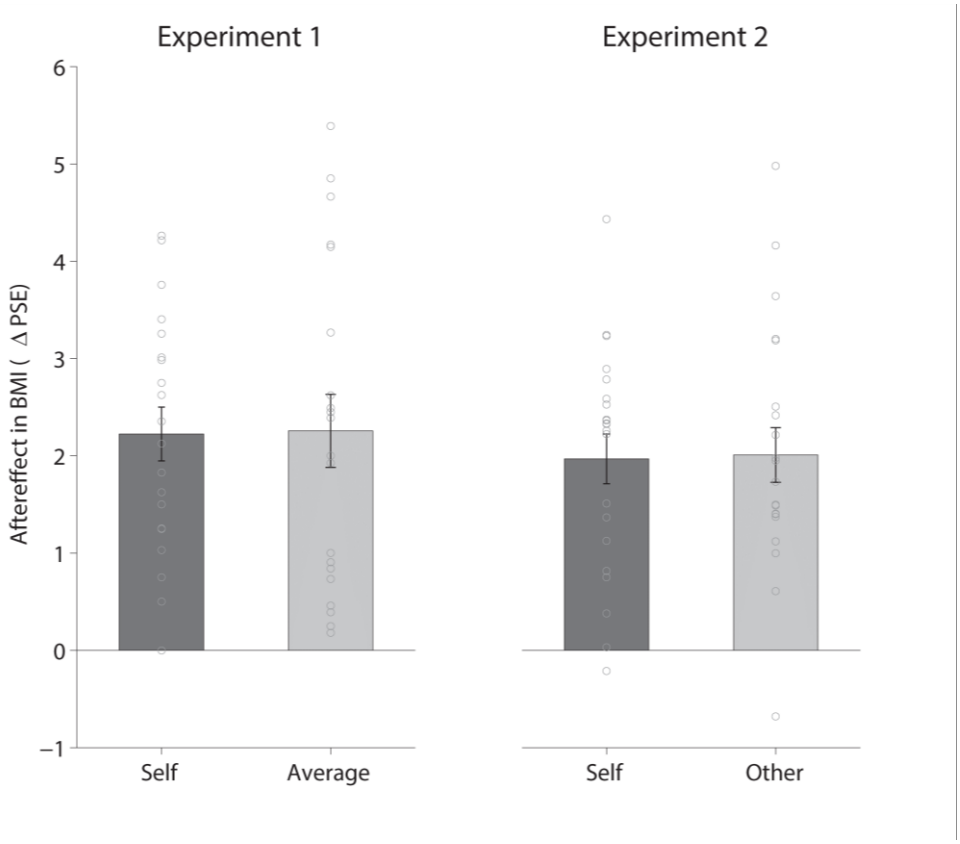

Figure 2.2: Results of Experiment 1 (left panel) and 2 (right panel). *Left panel*: the effect of adaptation for the *Self* and *Average* conditions shown as a Baseline/Adaptation change in PSE. The dots indicate individual subjects, and the error bars represent standard errors. Clear adaptation aftereffects were apparent for both body image judgments in the *Self* condition and judgments of typicality in the *Average* condition. The magnitude of the aftereffects was very similar in the two conditions. *Right panel:* the effect of adaptation for the *Self* and *Other* conditions presented in the same way as in Experiment 1.

Therefore, the results of the statistical analysis described above did not allow to reject the null hypothesis which states that there is no difference in the magnitude of the aftereffects in two experimental conditions (*Self* / *Average*). However, this type of analysis, namely frequentist statistics, do not allow to infer that there is indeed no difference between conditions on the population level, only that the data do not allow me to reject that possibility. To solve this issue and investigate whether my data supported the null hypothesis of no difference

between conditions I decided to conduct Bayes factors analysis. As opposed to traditional, frequentist analysis, Bayesian analysis allow to quantify to what extent the data support one hypothesis against the other in this case the null hypothesis against the alternative hypothesis (Dienes, 2016). I performed a Bayesian paired t-test (Rouder, Speckman, Sun, Morey & Iverson, 2009), comparing the PSE change (Baseline/Adaptation) between conditions, which provided support for the null hypothesis $BF_{(0, 0.7)} = 0.24$.

The absence of an overall effect of Self vs Average condition in Experiment 1 and the correlation of r=0.63 (p=0.003) between baseline responses in these conditions may suggest that most participants genuinely considered themselves as being about the average size, despite the fact that the average BMI of my participants (21.9) was much lower than the UK average for females in the same age range, which was reported to be 25.9 (Health Survey for England, 2016). Alternatively, the results may suggest that participants did not perform different tasks in the two conditions and possibly used themselves as a reference in both. I conducted Experiment 2 to address these issues.

2. 3. Experiment 2

The results of Experiment 1 revealed no main effect of the *Self* / *Average* condition. Therefore, I was not able to conclude that participants actually performed two different tasks in those two conditions. In Experiment 2, instead of the *Average* condition I designed a condition (*Other*), in which participants had to compare test stimuli with a specific person, namely the experimenter (myself) with whom participants interacted prior to performing the task. I reasoned that the use of a specific person rather than an abstract "average" person would make the task easier and clearer to the participants.

2. 3.1 Methods

Participants

Twenty-one participants (mean age: 29.9, SD: 10, range: 19-58; mean BMI: 23.7, SD: 4.8, range 17.0 – 35.0) took part in Experiment 2. All participants had normal or corrected to normal vision. All participants gave informed consent and were paid for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli and Procedures

Stimuli were identical to Experiment 1. Procedures were similar to Experiment 1. This time however, participants were asked to compare the images either with themselves, answering the question: *Is this body thinner or fatter than your own?*, or with me, answering the question: *Is this body thinner or fatter than Klaudia?* (*Other* condition). Before the start of the experiment participants had approximately 5 minutes of visual experience of me while I introduced the task. I was wearing close-fitting clothes and after explaining the task, I stood in front of the participant and asked them to memorize my body size and shape for about 10 seconds. As in Experiment 1, the experiment consisted of two parts: *Baseline* and *Adaptation*. Each part was divided into 4 blocks of 30 trials (2 blocks per *Self* / *Other* condition, in ABAB order, counterbalanced across participants). To shorten the length of the experiment, the duration of the adapting stimuli was reduced to 6 seconds, and the duration of the initial blank screen and the fixation cross before and after the response was reduced to 500 ms each.

2. 3. 2 Results and Discussion

Results from Experiment 2 are shown in Figure 2.2 (right panel). There were again clear adaptation aftereffects in both the *Self* condition (mean change: 1.97, SD: 1.17), $t(20) = 7.71$, $p < 0.001$, $d_z = 1.68$, and the *Other* condition (mean change: 2.01, SD: 1.29), $t(20) = 7.15$, $p < 0.001$, $d_z = 1.56$[1]. A 2x2 repeated measures ANOVA with factors condition and

[1] Because of a programming error, in some subjects, some of the thresholds that came close to the upper limit of possible stimuli could have suffered from a ceiling effect. In all cases, only one threshold per condition was affected (two were obtained), which made it possible to remove the affected thresholds in an additional analysis. Removing the affected thresholds (10.6 % of all thresholds) did not change

adaptation revealed a main effect of adaptation, $F(1,20) = 81.47$, $p < 0.0001$, $\eta_p^2 = 0.80$, showing that exposure to a thin body affected the perception of test bodies. I also found a significant main effect of condition, $F(1, 20) = 5.30$, $p = 0.032$, $\eta_p^2 = 0.21$, which reflects the fact that I was perceived differently (overall as thinner) than the participants perceived themselves. This difference between the two types of judgments is important as it demonstrates that participants were in fact making different judgments in the two conditions. Critically, however, there was no significant interaction, $F(1, 20) = 0.02$, $p = 0.9$, $\eta_p^2 = 0.00$, again suggesting that adaptation affected participants' perception of themselves in the same way it affected perception of the experimenter's body. As in Experiment 1, there was a positive correlation between the magnitude of the aftereffects in the two conditions, though it did not differ significantly from 0, $r = 0.35$, $p = 0.12$.

As in Experiment 1, a Bayesian paired t-test comparing the magnitude of the change in PSE in the two conditions provided additional support for the null hypothesis: $BF_{(0, 0.7)} = 0.23$, further suggesting that there was no difference in the magnitude of aftereffects between the *Self* and the *Othe*r condition.

These results showed that adaptation to an extremely thin body affected judgements about self vs other body similarly and therefore the magnitude of the aftereffects was not influenced by the type of judgement being made. However, previous research suggested that in some cases body adaptation may be affected by the task. Winkler and Rhodes (2005) showed that while adaptation to a thin body had an effect on both perceived normality and attractiveness of test bodies, adaptation to a fat body did not significantly affect perceived attractiveness. Thus, in Experiment 3, I also tested whether adaptation to fat bodies affected self vs other body judgements equally.

One possible limitation of Experiment 2 is the fact that I used myself as a reference in the Other condition. Although the pattern of results in this condition resembles typical adaptation aftereffects, it is possible that the responses were affected by some form of

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the overall pattern of the results. Imputing the affected thresholds using regression analysis also yielded very similar results.

participant bias or social desirability bias in which participants change their responses to more socially acceptable. Since judging another person's weight is a sensitive task and participant knew that I would eventually see their responses, it is possible that they altered their judgements not to offend me. Therefore, in Experiment 3, in which I tested the effect of both thin and fat exposure, I used a famous person (Kate Middleton) as a reference in the Other condition.

2. 4 Experiment 3

Experiment 3 aimed to test the effect of thin and fat adaptation on judgments about self and other bodies. This time, in the *Other* condition I used a famous person in the United Kingdom, i.e., Kate Middleton (the Duchess of Cambridge). I chose Kate Middleton as I expected that she would be familiar to a largest group of potential participants. In addition, KM has a BMI of about 18 which is lower than an average UK female (and indeed lower than 90% of participants in Experiments 1 and 2) which made the difference between the conditions most apparent.

2. 4.1 Methods

Participants

Eighteen participants took part in Experiment 3 (mean age: 27.1, SD: 7.3, range: 20 - 41, mean BMI: 20.2, SD: 2.2, range 17.0 – 25.4). Two additional participants who signed up for Experiment 3 were tested but their data was never analysed. One of them was pregnant and the other one had a BMI beyond the range of the stimuli. All participants had normal or corrected to normal vision. All participants gave informed consent and were paid for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli and Procedures

Procedures were similar to Experiment 2. However, in the *Other* Condition, participants were asked to compare the test images with Kate Middleton, answering the question: *Is this body thinner or fatter than Kate Middleton?* I made sure that all participants were familiar with the appearance of Kate Middleton prior to the experiment. Additionally, at the beginning of the experiment, participants were presented with 5 full body images and one portrait of Kate Middleton.

Unlike the first two experiments which involved only a thin adapting stimulus, Experiment 3 included both a thin (BMI 13) and a fat adaptor (BMI 35). The experiment therefore consisted of four parts: Baseline and Adaptation, each repeated twice, once with a thin and once with a fat adaptor. Each of these four parts was further divided in 4 blocks of 36 trials (2 blocks per *Self* / *Other* condition, in ABAB order, counterbalanced across participants). To further reduce the length of the experiment, initial adaptation was shortened to 1 minute, the top-up adaptation to 4 seconds, and the initial blank screen to 250 ms. Participants took a 10-minutes break between the two adaptation procedures (i.e., thin and fat) to allow the effect of adaptation to wear off. The order of thin/fat adaptation was counterbalanced across participants.

4.2 Results and Discussion

The results from Experiment 3 are shown in Figure 2.3. As in the first two experiments, clear aftereffects were apparent after adaptation to a thin body in both the *Self* condition (mean change: 2.78, SD: 1.71), $t(17) = 6.89$, $p < 0.001$, $d_z = 1.63$, and the *Other* (i.e., Kate Middleton) condition (mean change: 2.86, SD: 1.39), $t(17) = 8.76$, $p < 0.001$, $d_z = 2.07$. Similar aftereffects were also found after adaptation to a fat body. There were clear increases in judged BMI in the *Self* condition (mean change: - 2.78, SD: 1.34), $t(17) = -8.76$, $p < 0.001$, $d_z = 2.07$, and the *Other* condition (mean change: - 2.51, SD: 1.23), $t(17) = -8.67$, $p < 0.001$, $d_z = 2.04$. Thus, clear aftereffects were found for both thin and fat adapting stimuli, both for judgments of one's own body and of Kate Middleton's body.

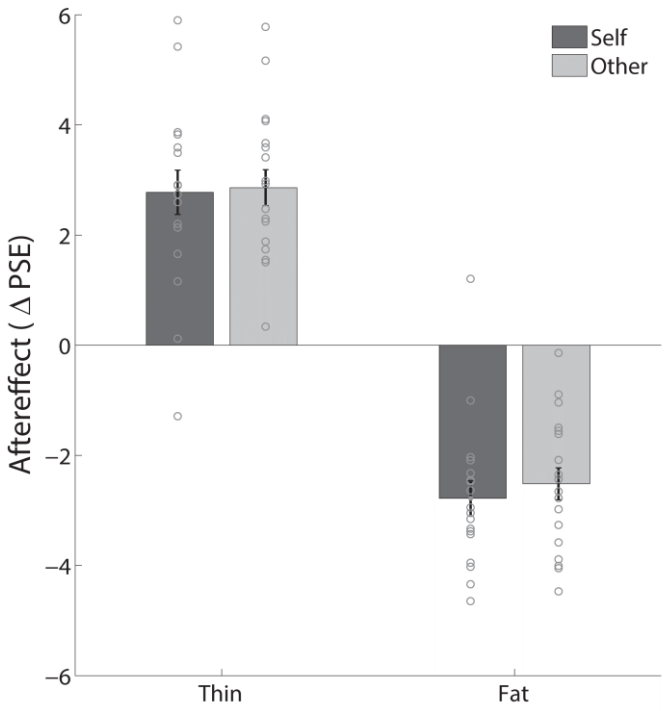

Figure 2.3: Results of Experiment 3. The effect of thin and fat adaptation for *Self* and *Other* condition. The grey dots indicate individual subjects and the error bars represent standard errors[2].

A 2x2x2 repeated measures ANOVA with factors: *condition* (*Self* / *Other*), *adaptation* (*Baseline* / *Adaptation*) and *adapting body type* (thin / fat) was performed on the PSEs. I found no main effect of adaptation, $F(1,17) = 0.22$, $p = 0.644$, $\eta_p^2 = 0.01$. There was however, a main effect of adapting body type, $F(1,17) = 102.34$, $p < 0.001$, $\eta_p^2 = 0.86$, and an interaction between adaptation and adapting body type, $F(1,17) = 187.26$, $p < 0.001$, $\eta_p^2 = 0.92$, showing that adaptation to thin vs fat bodies produced strong effects in opposite directions. I tested this

[2] Importantly, all but one participant showed aftereffect in the same (predicted) direction. Still, there were individual differences in the magnitude of these aftereffects. One possible, hypothetical explanation is that some participants were paying more attention to the adaptors than the others, or spent more time looking at body parts that are most affected by body size changes such as hips, waist, stomach or upper tights. It is important to note, that in my experiments I did not control for eye movements. Prior body size adaptation studies also used free viewing where participants are free to move their gaze across the presentation screen with no eye tracking (Winkler & Rhodes, 2005; Glauert et al., 2009; Hummel et al., 2012; Brooks et al., 2016). A possible future study using an eye-tracker could provide more insight into this issue. My prediction is that participants who during exposure focus on critical body parts such as hips and waist show strongest adaptation aftereffects.

assumption using 2 tailed paired t-tests directly comparing results of adaptation sessions to thin vs fat: $t(17) = -11.78$, $p < 0.0001$, $dz = -2.72$ for the *Self* condition, and $t(17) = -12.25$, $p < 0.0001$, $dz = -2.89$ for the *Other* condition. I also found a main effect of *Self* / *Other* condition, $F(1,17) = 11.65$, $p = 0.003$, $\eta_p^2 = 0.41$, clearly indicating that participants in the study perceived their bodies as different from Kate Middleton's (overall as fatter). The interaction between the *Self* / *Other* condition and the adapting body type (thin / fat) was also significant, $F(1,17) = 5.76$, $p = 0.028$, $\eta_p^2 = 0.25$. However, again there was no interaction between adaptation and *Self* / *Other* condition, $F(1,17) = 0.306$, $p = 0.587$, $\eta_p^2 = 0.018$, and no interaction between all three factors, $F(1,17) = 0.132$, $p = 0.721$, $\eta_p^2 = 0.08$. This indicates that adaptation affects participants' judgments of themselves in the same way it affected judgments of Kate Middleton's body. As in Experiments 1 and 2, there was a positive correlation between the magnitude of the aftereffects in the two conditions, though it did not differ significantly from 0: r = 0.33, p = 0.18 for the thin adaptation and $r = 0.22$, p = 0.38 for the fat adaptation.

Again, the results of the Bayesian paired t-test comparing the magnitude of the aftereffects in two conditions showed that data supports the null hypothesis for both, thin: $BF_{(0, 0.7)} = 0.25$, and fat adaptor: $BF_{(0, 0.7)} = 0.30$.

5. General Discussion

Body image dissatisfaction is a prevalent problem in modern societies (Grogan, 2017). Media are often blamed for creating unrealistic, unhealthy body ideals that can shape our beliefs and attitudes (Derenne & Beresin, 2006). Recently it has also been suggested that exposure to thin ideals can influence the way we actually perceive our own bodies. Several studies (Hummel et al., 2012b; Brooks et al., 2016) proposed visual adaptation as a model of media influences on one's own body image.

Here, I showed that adaptation affects judgements about one's own body in a similar way as judgments about other people's bodies, both when asking about typical bodies (Experiment 1), or about a specific other person's body (Experiments 2-3). Importantly, I

found a main effect of Self / Other condition in Experiments 2-3, indicating that participants complied with the instructions and were indeed making different comparisons when judging the test stimuli in Self and Other condition, comparing test images with either their own body or bodies of others. My results replicate previous findings showing that visual adaptation to extreme body types affects perception of bodies. The effect sizes in this study (range dz = 1.34 - 2.07) were very large and similar to those found in previous literature. For example, Hummel et al. (2012b) using similar task in two experiments obtained Cohen's dz = 2.87 and 1.04. Critically, however, I found virtually identical effects for judgments of other people's bodies. This suggests that adaption does not have specific effects on the participant's body image. I suggest instead that adaptation may have affected body size judgments by changing visual perception of the test stimuli.

My findings are consistent with the results of previous studies that reported transfer of body size aftereffects between different identities (Hummel et al., 2012b; Brooks et al., 2016). The authors of these studies suggest that their results reflect perceptual bias similar to those evoked by exposure to thin ideals in Western culture and that this bias may contribute to the development of body image disorders.

It is true that for visual adaptation to constitute an experimental model of body image distortion, some overlap of the representation of self and others is required to allow the transfer of aftereffects from media images to the perception of one's own body. However, if visual adaptation to bodies truly modulates one's own body image, then it should also differ from the general effect adaptation has on all images of bodies. If both the item being tested (own body) and the probe (other bodies) are equally affected by adaptation, the relative difference between them should not change. If all bodies are equally affected, adaptation to extreme body types cannot serve as a sufficient explanation for own body image distortion. If, however, adaptation affects perception of one's own body and other bodies differently, it may suggest that it affects higher level representation of one's own body and not only the experience of the visual image. Here, I found equally strong aftereffects for judgments about own body and other people

bodies. Thus, my results provide no evidence that body size adaptation has an effect that shows specificity to one's body image.

Hummel et al. (2012b) and Brooks et al. (2016) used both images of participants and other people as their stimuli. In my study, I used the exact same images in all conditions but changed the question that was asked and, therefore, varied the context. Interestingly, Winkler and Rhodes (2005) found that attractiveness aftereffects were observed following adaptation to extremely thin bodies but not following adaptation to fat bodies, whereas no such asymmetry was found when participates were asked to judge the perceived normality of the test image, suggesting that strength of adaptation aftereffects in some cases may depend on the type of judgement being made. Furthermore, de la Rosa et al. (2014) showed modulation of the aftereffects in action adaptation across conditions which differed in social context although the physical stimuli remained unchanged. These findings suggests that strength of adaptation aftereffects in some cases may be mediated by the context of the task. However, in my study, the specific judgement being made (i.e., about one's own body or about someone else's) did not affect the magnitude of the adaptation aftereffects.

I decided to ran a PSE estimation procedure with a 1AFC (one alternative forced choice task, characterized by only one stimulus presented at a time) as I was aiming to measure changes in subjective representations of body size. One objection against this method is that it does not allow to easily distinguish between perceptual bias (change in perception of the stimuli) and response bias (change in criterion for the decision). However, in my task, in both conditions I used the same stimuli, and therefore I expected the perceptual bias in appearance of the test stimuli to be the same, and the difference that what I was looking for could be seen as a form of response bias, i.e. change in criterion, depending on whether the participant was comparing the images to their own or other body. One possible way of distinguishing between perceptual and response bias would be to apply signal detection theory (STD) analysis in which hit rate (positive response to a stimulus/change that is there) and false alarm rate (positive response to a stimulus/change that is not there) are used to estimate change detection sensitivity and decision criterion separately (Kingdom & Prins, 2010). However, in my task

participants were asked to compare the stimuli to the internal, mental representations, i.e. to what they think their body or other bodies look like. Therefore, there were no correct or incorrect answers in this task and it did not call for STD analysis which rely on comparison of hits, misses, false alarms and correct rejections. It would be possible to design the experiment differently, using a certain image, with clearly defined body size parameters, as a reference and ask participants to compare test images to this reference. This would allow measurement of changes in perception of bodies but would not provide information about the mental body image of the participants. Another common method to estimate perceptual bias is a two alternative forced choice task (2AFC) which involves decisions between two stimuli presented on the same trial under different conditions, e.g. one stimulus on the left and other on the right. This method can be applied to low-level adaptation aftereffects that are thought to be specific to the location within visual field, i.e. an adaptor presented on the right side of the visual field will affect test stimulus presented on the right side but not on the left. It was not, however, directly applicable in my experiments as higher-level aftereffects have not been shown to be location specific (Zimmer & Kovacs, 2011) and I expected all test stimuli within the same comparison to be affected similarly.

One possible interpretation of my results is that visual adaptation affects visual perception of immediately perceived visual stimuli but not stored representations. I follow up on this question in the next chapter, where I investigate whether adaptation affects stored representation of one's body, i.e. body image, using an implicit Body Image Task (BIT, Fuentes et al., 2013).

Chapter 3 – Adaptation and implicit body maps.

3. 1 Introduction

In Chapter 2, I discussed the results of a series of experiments showing that body size adaptation affects representations of self and other people's bodies similarly. I distinguished two ways in which adaptation may affect body image judgements: 1) by affecting stored representations, 2) by affecting only the perception of the visual stimulus. I suggested that the results described in Chapter 2 may be explained by arguing that short-term visual adaptation rather than affecting stored representations, affects only the perception of the directly presented stimulus. Here, I wanted to test this assumption more directly by employing a task where no visual image is directly presented but where participant is required to retrieve an image from memory and recreate it on the screen. If adaptation affects stored representations, it should affect tasks that utilise this representation even if they don't involve a visual stimuli. If, in contrast, it affects only the visual perception of test stimuli, no such effects should occur.

Tasks used to measure body image can be divided into *depictive methods*, in which participants compare their body to a visual image (depiction of a body), and *metric methods*, in which participant compare some measure of their body to a metric standard, e.g. a line (Longo & Haggard, 2012). Depictive methods require explicit access to body image, whereas metric methods test body image implicitly. Experiments described in Chapter 2, used a task in which participants compared the stored representation of their body to a visual image and therefore belonged to depictive methods which test explicit access to the body image. Here, I used a way to implicitly measure perceived size of body parts and overall body configuration, i.e. the Body Image Task (BIT), which was recently developed by Fuentes, Pazzaglia, Longo, Scivoletto and Haggard (2013a). In this task, participants are shown a single body part (usually a head) on a monitor as an anchor stimulus and are asked to judge the relative location of several other body parts by clicking on the corresponding location on the monitor. The

positions of each landmark are then used to construct an implicit perceptual map of bodily structure and perceived size of the body. This method qualifies as an implicit measure of body image because individual judgements refer only to the locations of body parts, although the map that finally emerges is a depiction of the whole body.

In the present study, participants performed the Body Image Task three times: before, during and after adaptation to a thin body, which resulted in three separate maps. I then calculated the distance between different body landmarks to get the estimated length of different body parts e.g. waist and hips. I then compared these lengths between different adaptation conditions. I predicted that if visual adaptation affects stored representations, the maps emerging from the task in the adaptation condition will be biased towards the adapting stimulus i.e. after exposure to a thin body, the emerging map will be thinner than it was before adaptation. I included a post adaptation condition in order to check whether any effect is due to adaptation manipulation and not task repetition. I predicted that the results in the post-adaptation part should be similar to pre-adaptation (baseline). These results would suggest that adaptation not only affects what is immediately perceived but also influences the underlying representations.

3. 2 Methods

Participants

As in the previous experiments, I restricted my sample to female participants, due to the nature of the adapting stimulus depicting a female body. Twenty one participants took part in Experiment 1. One participant was excluded from the analysis when it became clear after the experiment that she misunderstood the instructions. I analysed the data of the remaining 20 participants (age = 27.75, range 21-58, average BMI = 22.42, range 19-31.9). All participants gave informed consent. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli

As an adaptor, I used an image of a thin body (BMI = 13) facing straight ahead (see Figure 3.1 A) rendered from the avatar created in Daz 3D and used in previous experiments.

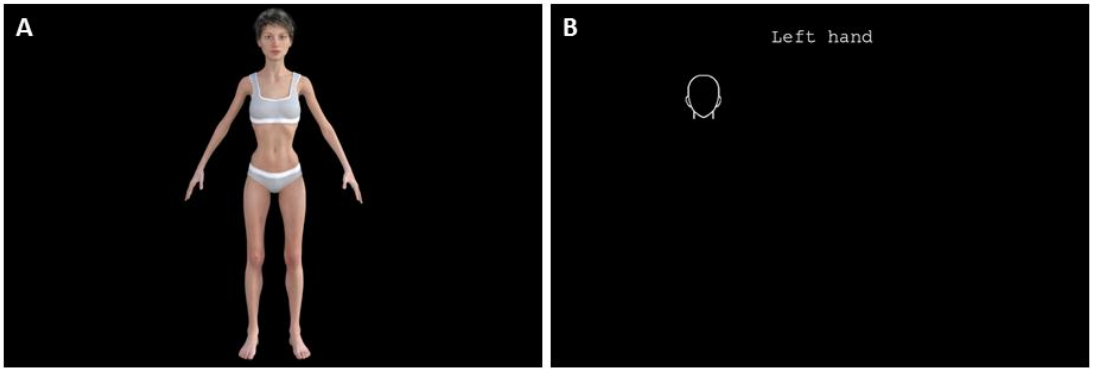

Figure 3.1: Task in the *Adaptation* part of the experiment. On each trial participants first saw the adaptor for 6 seconds. Then the saw a black screen with an anchor (head) and a cue indicating which position they should localize.

Procedures

Participants performed a computer task, sitting approximately 50 cm from the screen with head movements unrestricted. The task was presented using Psychtoolbox (Brainard, 1997), running on MATLAB (Mathworks, Natick, MA). The images were presented on a 24-inch screen, on a black background. The height of the adapting body was 25 cm (28° visual angle).

The experimental session consisted of three parts (adaptation conditions): *Baseline*, A*daptation* and *Post-adaptation* parts. In order to shorten the length of the experiment, I only ran adaptation using a thin adaptor. To make sure that any effect obtained in the *Adaptation* part, was due to the exposure to the adaptor and not caused by task repetition, I added the *Post-adaptation* part. There was a 10-minute break between A*daptation* part and *Post-adaptation* to allow the effect of adaptation to wear off. In each part, participants performed the Body Image Task (BIT, Fuentes et al., 2013a; 2013b) in which they were asked to localize a position of a specific body part relative to an anchor (the head) shown on the screen. The height of the

anchor was approximately 3 cm (3° 26' visual angle). Fourteen body parts were tested: left shoulder, right shoulder, left elbow, right elbow, left waist, right waist, left hand, right hand, left hip, right hip, left knee, right knee, left foot, and right foot. I used the same body parts as Fuentes et al. (2013b) with an addition of the waist which seems to be especially important in the perception of female shape (Singh, 1993). Each of the 14 body parts was presented five times in a randomized order, resulting in 70 trials per adaptation condition (210 in total).

In the Baseline part, on each trial, a written instruction was shown on the top of the screen (a cue), indicating the body part that the participant were asked to localize. The outline of a head (an anchor) was shown in one of five positions under the cue (see Figure 3.1 B for example). The cue and the anchor stayed on the screen until participants' response. Participants made their judgment of the relative location of the indicated body part with a mouse click and the new trial began. After each response, the mouse cursor appeared again at a random location on the monitor to reduce hysteresis and make responses as independent from each other as possible.

In the Adaptation part, participants first passively view a thin adaptor presented at the centre of the screen for 2 minutes. Then participants performed the task again. On each trial the adaptor was additionally presented for 6 seconds, followed by the task display (Figure 3.1). The Post-adaptation part was identical to the Baseline. There was a 10-minute break between Adaptation and post-adaptation condition. There is no systematic research on the exact duration of short-term body size aftereffects. The 10-minute break was a practical decision dictated by the overall length of the experiment. Therefore, it is possible that there was a carry-over effect of adaptation in the post-adaptation session. However, in my other experiments where I tested adaptation to thin and fat body within the same session, also 10 minutes apart, I did not find significant difference between baselines suggesting that 10 minutes can be enough for adaptation to diminish.

At the end of the experiment, a photograph of each participant, standing up with arms outstretched, was taken to obtain the actual location of body parts. Body parts that were hidden from view by clothing (e.g. waist) were marked with yellow stickers placed on the cloths.

Analysis

I closely followed the analysis described by Fuentes et al. (2013b). First, for each participant, I calculated the average judged position of each body part in each adaptation condition. I excluded the responses beyond two standard deviations of the mean, as well as responses that confounded left and right sides of the body (on average, 2.5 % of the trials per participant). Then, I used Bookstein coordinates (Bookstein, 1991) to transform participants' average reported body part locations into a common frame of reference. To calculate Bookstein coordinates two landmarks are selected to have coordinates (0, 0) and (0, 1), and all other points are scaled accordingly. Here, I took the point midway between the eyes as (0, 0) and the point midway between the feet as (0, 1). Next, I used this distance, representing judged height, to transform each body map into a common space without changing the relative proportions of different body parts, i.e. I normalized all judged locations as a proportion of judged height. I applied the same transformations to the actual locations of participants' body parts obtained from the photographs taken after the experiment. This allowed me to compare the relative size of different body parts across participants and conditions, as well as perceived maps and actual maps.

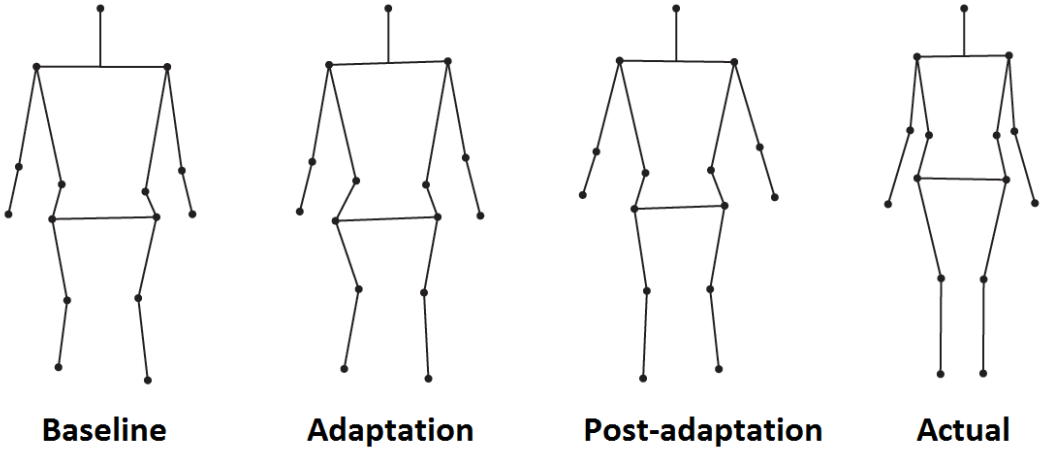

Figure 3.2: Body maps. The figure shows perceived body image maps in all adaptation conditions as well as the actual body map (averaged across participants).

For each body map, I calculated the following body dimensions by measuring distances between pairs of points:

- Shoulder width (left shoulder to right shoulder)
- Waist width (left waist to right waist)
- Hip width (left hip to right hip)
- Torso length (shoulder to hip), left and right
- Upper arm length (shoulder to elbow), left and right
- Lower arm length (elbow to hand), left and right
- Upper leg length (hip to knee), left and right
- Lower leg length (knee to foot), left and right

Finally, I averaged the dimensions that were calculated separately for each side of the body to get a single estimate and I added the length of the upper and lower arm and leg. This resulted in six body size estimates: shoulders width, waist width, hips width, torso length, arm length and leg length, for each adaptation condition.

3. 3 Results and discussion

Figure 3.2 shows the average body image map in each adaptation condition. The actual body map is shown in Figure 3.3. I first compared the body image dimensions between the actual map and the perceived map at baseline. For each of the six body size estimates (shoulders width, waist width, hips width, torso length, arm length and leg length), I ran a t-test comparing the perceived map at baseline with the actual map. I found that participants overestimated the width of the shoulders relative to the height: $t(19) = 4.49$, $p < 0.001$, $d_z = 1.00$, as well as the length of the torso: $t(19) = 3.91$, $p < 0.001$, $d_z = 0.87$. They also underestimated the length of the legs: $t(19) = 4.49$, $p < 0.001$, $d_z = 1.00$. The other comparisons were not significant after Bonferroni correction. The results were consistent with findings by Fuentes et al. (2013b) which showed the same overestimation the width of the shoulders and the length of the torso, and underestimation of the length of the legs.

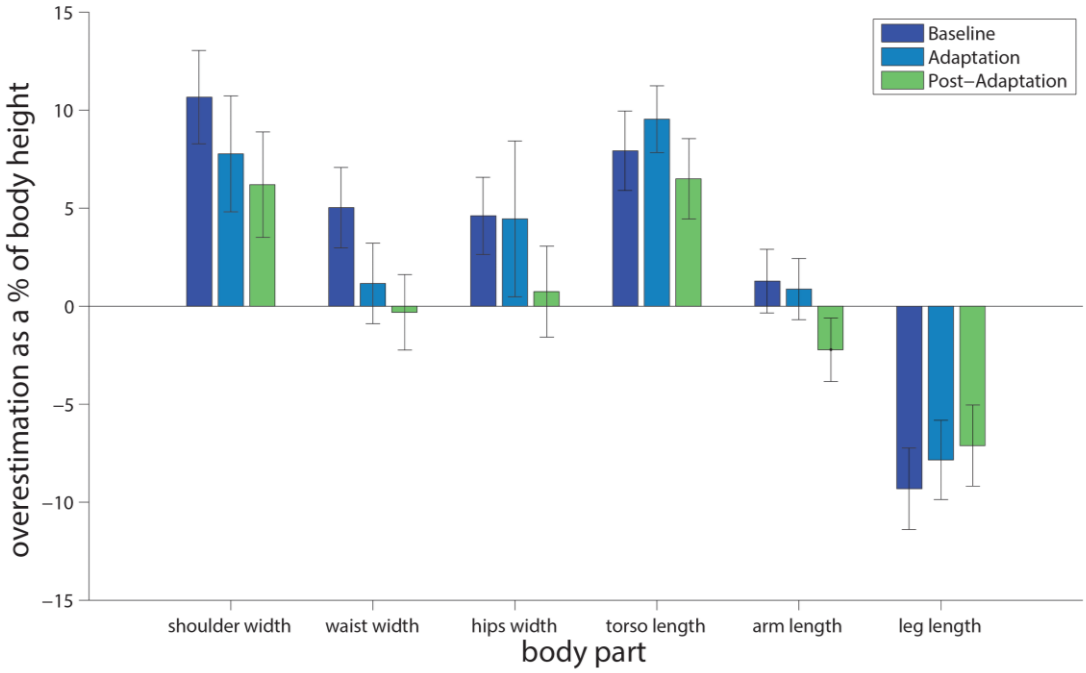

Figure 3.3: Results of the experiment. Deviation from the actual measurement for each body part expressed as a percentage of body height. Positive values represent overestimation and negative values – underestimation. Error bars represent standard errors.

I then compared the body image dimensions between adaptation conditions, to test whether exposure to a thin body had an effect on implicit body image. I conducted the analysis for the body parts where the width was measured (shoulders, waist and hips) separately from the body parts where I measured the length (arm, legs, torso). I expected that exposure to a thin body should mostly affect the width of the waist and hips but not the length of the torso, arms and legs.

First, I ran a 3 x 3 repeated measures ANOVA with factors *adaptation condition* (*Baseline*/ *Adaptation*/ *Post-adaptation*) and *body part* (*shoulders width*/ *waist width*/ *hips width*). The results revealed significant main effects of condition: $F(2, 38) = 7.52$, $p = 0.002$, $\eta_p^2 = 0.28$, and body part $F(2, 38) = 25.77$, $p < 0.001$, $\eta_p^2 = 0.58$, but no interaction $F(4, 76) = 0.88$, $p = 0.48$, $\eta_p^2 = 0.04$. However, post-hoc comparisons (Bonferroni corrected) revealed that there was no significant difference between Baseline and Adaptation condition: $t(19) =$

1.94, $p = 0.172$. There was however, a difference between Adaptation and Post-adaptation: $t(19) = 2.56$, $p = 0.04$, and Baseline and Post-Adaptation: $t(19) = 4.56$, $p < 0.001$.

The width estimates for all three body parts (shoulders, waist, hips) gradually decreased between the adaptation conditions (see Figure 3.4). This pattern of results suggested that the effect of condition was not caused by the adaptation aftereffects but possibly by task repetition. Alternatively, it could be argued that the effect of adaptation did not wear off after the 10-minute break, which would explain the significant difference between Baseline and Post-Adaptation. There is no systematic research on the exact duration of short-term body size aftereffects. The 10-minute break was a practical decision dictated by the overall length of the experiment. Therefore, it is possible that there was a carry-over effect of adaptation in the post-adaptation session. However, in my other experiments where I tested adaptation to thin and fat body within the same session, also 10 minutes apart, I did not find significant difference between baselines suggesting that 10 minutes can be enough for adaptation to diminish. Furthermore, there was also a significant difference between Adaptation and Post-Adaptation conditions, which went in the same direction as difference between Baseline and Adaptation, and since there is no reason why the absence of the adaptor would make the effect of adaptation stronger, it seems unlikely that his difference was caused by adaptation.

Next, I ran a 3 x 3 repeated measures ANOVA with factors *adaptation condition* (*Baseline*/ *Adaptation*/ *Post-Adaptation*) and *body part* (*torso length/ arm length/ leg length*). The results revealed the main effect of condition: $F(2, 38) = 4.57$, $p = 0.017$, $\eta_p^2 = 0.19$, but no effect of body part $F(2, 38) = 2.81$, $p = 0.073$, $\eta_p^2 = 0.13$, and no interaction $F(4,76) = 2.46$, $p = 0.052$, $\eta_p^2 = 0.12$. Again, post-hoc comparisons (Bonferroni corrected) revealed that there was no significant difference between Baseline and Adaptation condition: $t(19) = 1.10$, $p = 0.828$. There was also no significant difference between Adaptation and Post-adaptation: $t(19) = 1.22$, $p = 0.686$, and Baseline and Post-Adaptation: $t(19) = 2.44$, $p = 0.053$. These results show no evidence for the effect of visual adaptation on the BIT.

Looking at the pattern of results (Figure 3.4), I suspected that participants became more accurate in their responses with each task repetition. To test this hypothesis and assess

the similarity of the overall shape of the body map obtained in each condition with the actual map, I used Procrustes alignment (Rohlf & Slice, 1990). This analysis was modelled on that used in Longo and Golubova (2017). Procrustes alignment superimposes spatial configurations of homologous landmarks using translation, scaling, and rotation to minimize the difference between the landmarks and align them as closely as possible. The square-root of the residual sum of squared distances between pairs of homologous landmarks which is not removed by Procrustes alignment provides a measure of the dissimilarity in shape between the two configurations, called the Procrustes distance. Thus, a Procrustes distance of zero indicates that two configurations have the exactly same shape, while a Procrustes distance of 1 indicates the maximal possible difference (i.e., the configurations contain no shared shape).

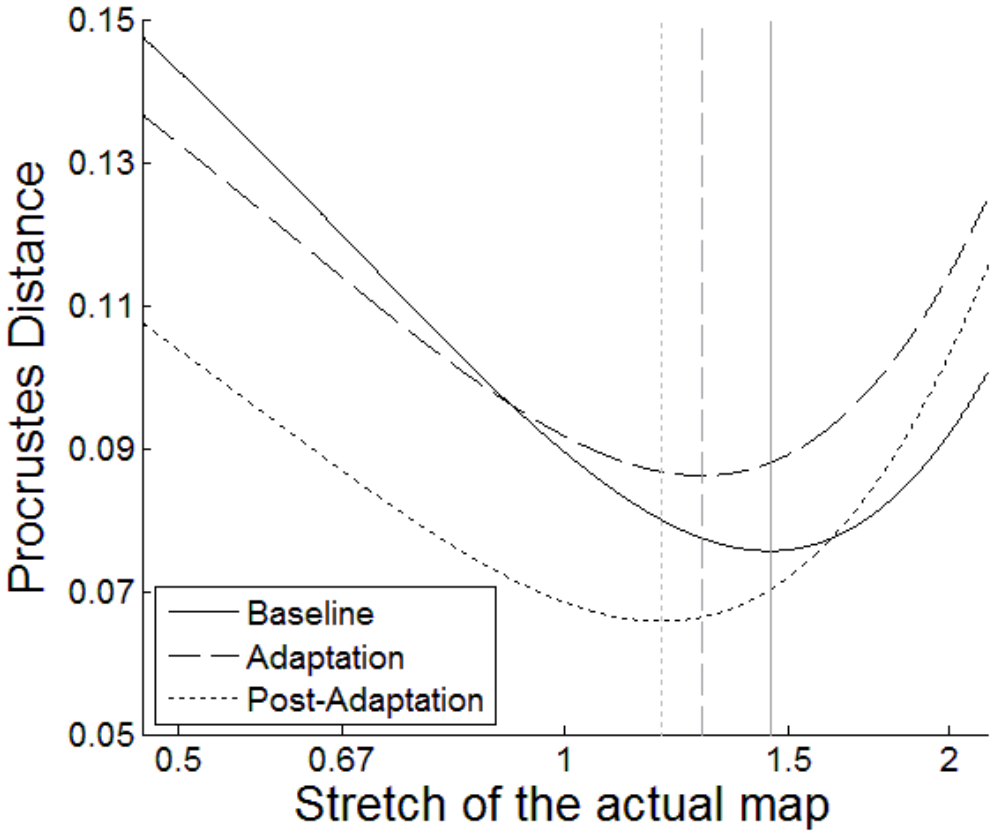

Figure 3.4: Results of the Procrustes analysis. The figure shows the mean Procrustes distance between perceived map in each condition and the actual map stretched by different amounts. A stretch of 1 indicates the actual map; stretches greater than 1 indicate stretch in the horizontal axis, while stretches

less than 1 indicate stretch in the vertical axis. The vertical lines indicate the mean of the best-fitting stretches in each condition. The closer the mean of the best-fitting stretches is to 1, the more similar it is to the actual map.

Here, I stretched the actual map of each participant representing the locations of the 10 landmarks (left shoulder, right shoulder, left waist, right waist, left hip, right hip, left knee, right knee, left foot, and right foot) [3] by different amounts to find the stretch that minimized the Procrustes distance with each participant's perceptual map, in each condition. I tested values between 0.33 and 3.5 by exhaustive search with a resolution of 0.0005 units in natural logarithm space which resulted in 4723 steps. As a result of Procrustes alignment, I obtained a single value per participant in each condition, representing the stretch of the actual map that was optimally aligned with the perceptual map.

Analysis of this data, conducted in logarithm space, revealed a significant difference in overall shape between the actual body map and the perceived body map in the *Baseline* condition: M = 1.45, , $t(19) = 5.75$, $p < 0.001$, $d = 1.29$. There was also a difference in the *Adaptation* condition: M = 1.31, $t(19) = 2.42$, $p = 0.026$, $d = 0.54$, but not in *Post-Adaptation*: M = 1.29, $t(19) = 1.49$, $p = 0.152$, $d = 1.29$.

A repeated measures ANOVA with a factor of condition show a significant main effect: $F(2,38) = 11.99$, $p < 0.001$, $\eta_p^2 = 0.39$. Post hoc comparisons revealed a significant difference between *Baseline* and *Adaptation*: $t(19) = 2.84$, $p = 0.032$, $d_z = 0.63$, between *Adaptation* and *Post-Adaptation* $t(19) = 2.94$, $p = 0.025$, $d_z = 0.66$, and between *Baseline* and *Post-Adaptation*: $t(19) = 4.02$, $p = 0.002$, $d_z = 0.90$ (Bonferroni corrected). These results show that body image map in the *Adaptation* and *Post-Adaptation* condition are more similar to the actual map than the map at *Baseline*, suggesting that with each repetition of the task participants became more accurate.

[3] I removed the arms from the analysis to minimize the effect of posture on the overall shape of the body map.

Together, these results suggests that exposure to the thin adaptor did not affect the performance on the BIT providing no evidence for short-term effects of visual adaptation on stored body representations, i.e. body image.

In the experiment presented in this chapter, I replicated findings by Fuentes et al. (2013), showing that people overestimate the width of the shoulders and the length of the torso, and underestimate the length of the legs. However, performance in the BIT did not seem to be affected by visual adaptation to a very thin body. I found no effect of adaptation on the implicit maps that emerged from BIT suggesting that adaptation does not affect stored body image. Thus, these results seem to be consistent with the findings described in Chapter 2.

In the introduction to this chapter, I discussed a distinction between explicit and implicit body image measures and argued that the task used in this experiment qualifies as an implicit measure because individual judgements refer only to the locations of body parts. Therefore, unlike explicit measures which use template matching, this method relies on local rather than holistic processing. Holistic processing, in which internal components of an object are automatically integrated in one unit, is seen as a hallmark of face perception (Tanaka & Farah 1993) but recent studies suggest that at least some aspects of body perception also rely on holistic processing (Aviezer, Trope & Todorov, 2012; Harris, Vyas, & Reed, 2016). It is possible that body size adaptation affects holistic rather than local processing and therefore did not affect judgements in the task used in the present experiment. One way of addressing this question, would be to use individual body parts as adaptors in the Body Image Task and this remains an open question for future research. Another way would be to test whether adaptation transfers between images of entire bodies and body parts. I investigate this question in 4 experiments presented in Chapter 5, and show results suggesting that body size aftereffects at least partially transfer between bodies and body parts. It is therefore possible that body size adaptation affects both holistic and local processing of bodies. Before I discuss this topic in more detail, in Chapter 4 I will present my results showing adiposity aftereffects in perception of faces alone.

Chapter 4: Adaptation to facial adiposity.

4. 1. Introduction

In Chapter 1, I described a growing body of literature reporting adaptation aftereffects in perception of faces for features such as gender, identity, attractiveness and emotional expression (MacLin, Nelson, & Webster, 1996; Rhodes, Jeffrey, Watson, Clifford & Nakayama, 2003; Watson & Clifford, 2003; Webster, Kaping, Mizokami, & Duhamel, 2004). Moreover, some classical studies investigated how adaptation affects pure physical appearance of faces. For example Webster and MacLin (1999) showed that adaptation to faces with consistent distortions, i.e., compressing or expanding the center of a face, causes normal faces to appear distorted in the opposite direction.

It has not been shown, however, how adaptation affects the perceived adiposity level of faces. Studies on adiposity aftereffects focus exclusively on bodies (Winkler & Rhodes, 2005; Glauert, Rhodes, Byrne, Fink, & Grammer, 2009; Hummel, Rudolf, Untch, Grabhorn & Mohr, 2012b; Brooks, Mond, Stevenson & Stephen, 2016). Adiposity seems to be linked to the appearance of the body and not so much the face alone. Intuitively, the face does not seem like the first place to store fat. It may seem natural to assume that in order to judge someone's body size the observer should be able to see the entire body. However, previous research suggests that people are able to judge body mass from the face alone. For example, in a study by Coetzee, Perrett and Stephen (2009), participants were shown face images and asked to make judgements about photographed individuals rating their weight on a Likert scale (0 = very underweight; 3 = average weight; 6 = very overweight). The results showed that participants' judgements were correlated with the actual BMI of the photographed individuals suggesting that people can categorize bodies according to their weight based on faces alone. Furthermore, Coetzee, Chen, Perrett and Stephen (2010), using the same task, identified facial

features (width-to-height ratio, perimeter-to-area ratio, and cheek-to-jaw-width ratio) which correlated with both perceived weight as well as the actual BMI of the photographed individuals, suggesting that in making adiposity judgements people use cues that are a reliable indicator of body mass.

In this chapter, I present an experiment which I designed to investigate whether exposure to a gaunt face affects perception of subsequently presented faces, causing aftereffects similar to those well documented in body adaptation literature (Winkler & Rhodes, 2005; Glauert at al., 2009; Hummel et al., 2012b; Brooks et al., 2016). Participants were presented with faces of different adiposity levels (Figure 4.1) and had to decide whether the face they were looking at was thinner or fatter than average. Participants performed the task before and after adaptation to a very thin face. I expected that, like in body adaptation studies, after adaptation test stimuli would appear fatter as compared to baseline and thus the judgement about the most average stimuli would be shifted towards the thin adaptor.

4. 2. Methods

Participants

Due to the nature of my stimuli (depicting only female faces) I restricted the sample to female participants. Twenty participants (mean age: 26.4, range: 20-53) took part in this experiment. All participants gave informed consent and were paid for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli

I used one hundred images of the same identity face that differed in adiposity level. First, I created three base images: thin, neutral and fat in Daz Studio 4.8 (DAZ Productions, http://www.daz3d.com/). As the neutral face (Figure 4.1, 50%), I used a face from a default Genesis female 3 avatar. I created the thin (Figure 4.1, 0%) and the fat (Figure 4.1, 100%) faces in Daz by adjusting parameters related to adiposity to be maximally low and high

respectively. Then, I morphed these base images using FantaMorph 5 (Abrosoft, http://www.abrosoft.com/) to create a spectrum of one hundred images ranging from thin (0%) to fat (100%) (see Figure 4.1 for examples).

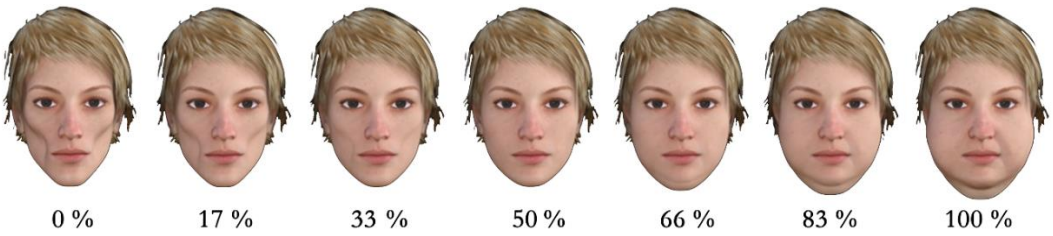

Figure 4.1: Examples of stimuli used in experiment. The same identity face was adjusted to differ in adiposity level. The percentages indicate the degree of morph between the thin (0%) and the fat face (100%). The 0% morph was used as an adaptor.

Procedures

Participants performed a computer task, sitting approximately 50 cm from the screen with head movements unrestricted. The task was presented using Psychtoolbox (Brainard, 1997), running on MATLAB (Mathworks, Natick, MA). The images were presented in the center of a 24-inch screen, on a black background. The height of each image was approximately 18 cm (20° visual angle). The responses were made using keyboard keys.

The experiment was divided into the *Baseline* and the *Adaptation* phase, each consisting of 60 trials. In both conditions, on each trial participants judged presented faces by answering the question: *Is this face thinner or fatter than average?* Before the start of the task, I explained to participants that "average" in this context means the most common/typical face for their age and gender (according to their best guess). The point of subjective equality (PSE, i.e., the stimulus for which the participant was equally likely to judge it as fatter or thinner than average) was calculated for each condition twice (based on 30 trials each) using a Bayesian adaptive method QUEST (Watson, 1983).

In the Baseline phase, each trial began with a blank screen (250-ms) followed by the test face (1000-ms) selected by QUEST from a set of possible stimuli based on the responses on previous trials. The screen remained blank until the response was made. A black cross (500-ms) indicated the end of the trial. The Adaptation phase started with an initial exposure when participants first passively viewed an image of a very thin face (Fig. 4.1, 0% morph) which was shown on the screen for approximately 2 minutes (4.5 s with a 200 ms break repeatedly for 30 times). The thin adaptor was again presented for 4 seconds followed by a fixation cross (1 s) before each test image to ensure that adaptation was sustained during the entire experiment. The rest of the trial was the same as in the Baseline phase.

4. 3. Results and discussion

Results from the experiment are shown in Figure 4.2. The PSE (expressed in % morph between thin and fat face) representing the face perceived as most average at baseline was M = 55.26: SD = 4.39. After adaptation to a very thin face, PSE decreased to M = 43.49: SD = 10.30. This difference was significant: $t(19) = 5.37$, $p < 0.0001$, $d_z = 1.20$.

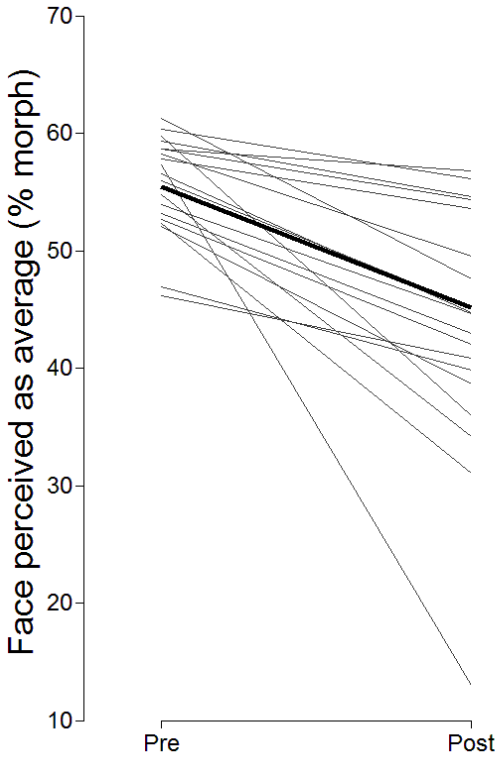

Figure 4.2: Results of facial adiposity adaptation. The grey lines indicate individual subjects and the mean is shown in black. There was a clear effect of adaptation to a thin face, indicated by the shift of the PSE towards the thin adaptor. The perceived averageness is expressed in the percentage of morph between very thin and very fat face, higher numbers represent higher adiposity levels.

The shift of the perceived averageness towards the thin adaptor was consistent with my predictions and indicated that after adaptation participants judged test faces (including the face previously perceived as most average) to be fatter than before adaptation. This result shows that face adaptation produces adiposity aftereffects that are similar to those observed in body adaptation.

Previous studies showed that people can broadly categorize bodies on the weight continuum based on faces alone (Coetzee, Perrett & Stephen, 2009; Coetzee, Chen, Perrett & Stephen, 2010). However, in both studies participants rated the images according to broad categories (e.g. “very underweight”, “average weight”, “very overweight”). Since categories

such as “average weight” encompass BMIs as diverged as 19 and 24, the results provide only limited evidence of how accurate people are in generalizing body size from faces. It remains unclear how precise people are in making these judgements. Future research should further investigate the relationship between the perceived facial adiposity and actual body mass.

My results show, for the first time, that observers can adapt to the adiposity level of faces. This finding seems particularly important when we consider how many faces we encounter each day, not only in our environment but also in media. Especially through social media an average person is exposed to a great number of face images each day.

In the next chapter, I will discuss a series of experiments investigating transfer of adiposity aftereffects between full bodies and body parts, especially faces.

Chapter 5: Cross-category adaptation between bodies and body parts

5. 1. Introduction

As I discussed in Chapter 1, adaptation aftereffects have been demonstrated and widely studied for low level features such as orientation or contrast and recently many studies showed higher level aftereffects for complex stimuli such as faces, bodies and objects. Studies on higher level aftereffects suggest that adaptation is not limited to low level sensory features but may affect higher level, more abstract representations. Still in most of these studies, the adapting and test stimuli are very similar and only differ along a single dimension, e.g. bodies of the same identity which differ only in body size, which raises the question whether even the higher level aftereffects result from adaptation to low level features of the stimuli.

Recently, some studies showed that adaptation aftereffects can transfer between stimuli belonging to different categories. For example, Ghuman, McDaniel and Martin (2010) showed that adaptation to bodies affects perception of subsequently presented faces in the direction opposite to the adaptor for features such as gender and identity. After exposure to male bodies, neutral looking faces were perceived as more female and vice versa. In consequence the point of subjective equality (PSE) on the continuum between male and female face was shifted towards the male adaptor. Similarly, after exposure to bodies of a certain identity, the PSE on the morphed continuum between two faces (of which one matched the identity of the adaptor) was shifted towards the identity of the adaptor. Furthermore, the authors showed that the strength of the aftereffects in their study depended on the length of the exposure to the adaptor which is one of the main characteristics of sensory adaptation. The cross category transfer reported by Ghuman et al. (2010) also seems to be specific to bodies and body parts (faces). The authors tested whether gender aftereffects transfer between faces and objects which are typically associated with specific gender, but found no effect of cross adaptation between faces and gender-specific objects. Palumbo, D'Ascenzo and Tommasi

(2015) reported similar aftereffects from faces to bodies. In their study, exposure to female faces biased perception of the gender of bodies towards the adaptor. Taken together, these studies suggest that gender adaptation does not rely on low-level features of the stimuli, but affects higher level representations.

These findings raise the question whether adaptation to body adiposity can transfer between full bodies and body parts which do not share the same low-level visual properties. In our daily life, both in our environment and in media, we often see bodies that are only partially visible and partially occluded, e.g. people sitting behind desks, headshots and partial body photographs in magazines. In my project, I was interested whether these partial images, specifically faces, can induce body size adaptation.

The results of the face adaptation experiment, which I described in the previous chapter, showed that people can adapt to adiposity level of faces and that this adaptation produces aftereffects in the same direction that were previously reported in body size adaptation literature. It has been also shown that exposure to thin or fat bodies affects preferences for facial adiposity (Re, Coetzee, Xiao, Buls, Tiddeman, Boothroyd and Perrett, 2011). In a series of experiments discussed in this chapter, I investigated whether body size aftereffects transfer between whole bodies and body parts.

5. 2. Experiment 1

In Experiment 1, I investigated whether adiposity aftereffects transfer between faces and bodies. Participants were adapted to a thin/fat face but then asked to make judgements about adiposity of subsequently presented test bodies.

5. 2. 1 Methods

Participants

As in all the experiments described in previous chapters, I restricted my sample to female participants, due to the nature of the stimuli depicting female bodies and faces. Twenty

participants (mean age: 25.4, range: 20-46) took part in Experiment 1. All participants gave informed consent and were paid for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli

Test bodies

I used the same set of 89 images of female bodies that I created for a series of experiments described in Chapter 2 (see Figure 2.1). This time, however, the stimuli were displayed on the screen with a head cropped out, so the face was not visible, to make sure that any effects were due to the transfer between faces and bodies and not caused by face adaptation.

Adapting faces

The adapting images were thin and fat face created using Daz Studio 4.8 (DAZ Productions, http://www.daz3d.com/). As a base image, I used a neutral looking face of average adiposity from a default Genesis female 3 avatar and altered it to appear very thin and very fat (Figure 5.1). I used the same avatar as in Chapter 3 with the same parameters for fat and thin face. Here, both faces were rotated at approximately 45° to match the orientation of the test bodies. 2D images were rendered from the 3D avatars.

Figure 5.1: Adaptors used in Experiment 1.

In creation of the adapting faces, I used the most extreme adiposity settings allowed by the software. Previous research on adaptation has shown that stimuli that are most extreme, i.e. most removed from the norm, elicit the strongest adaptation effects (REF).

Procedures

Participants performed a computer task, sitting approximately 50 cm from the screen with head movements unrestricted. The task was presented using Psychtoolbox (Brainard, 1997), running on MATLAB (Mathworks, Natick, MA). The images were presented in the center of a 24 inches screen, on a black background. The height of each image was approximately 18 cm (20° visual angle).

The experiment consisted of four parts: the *Baseline* and *Adaptation* phase, each repeated twice, once with a thin and once with a fat adaptor. There were 72 trials in each part (288 in total) and two PSE's were calculated based on 36 trials each using QUEST (Watson, 1983). In the Baseline phase, participants judged test images of bodies from the BMI spectrum 13-35, on each trial answering the question: *Is this body thinner or fatter than average?* Before the start of the task, I explained to participants that "average" means the most common/typical body for their age and gender (according to their best guess). Participants responded with their right hand using left (thinner) and right (fatter) arrow keys on the keyboard.

Each trial began with a blank screen (250-ms) followed by the test body (1000-ms). Then, the screen remained blank until the response was made. A black cross (500-ms) indicated the end of the trial. In the Adaptation phase participants first passively viewed an image of either a very thin or a fat face (see Figure 5.1) for 2 minutes. The adaptor flickered every 4 seconds (disappearing for 500 ms and appearing again) to maintain attention. After this initial adaptation, participants performed the same task as in the Baseline phase. The task in the Adaptation phase was identical to the Baseline with the addition of a 'top-up' adaptation: on each trial the face adaptor was again presented for 6 seconds, followed by one second of blank screen, to ensure that adaptation was sustained during the entire session. The procedure was repeated for the adaptor from the opposite side of the thin-fat spectrum with a 10-minutes

break in-between to allow the effect of adaptation to wear off. The order of thin/fat adaptation was counterbalanced across participants.

5. 2. 2 Results and discussion

In each adaptor type condition (thin / fat), two 50% thresholds (PSEs) per adaptation phase (*Baseline* / *Adaptation)* were calculated using QUEST to estimate the BMI at which participants were equally likely to respond thinner or fatter. These two thresholds were then averaged, resulting in 4 PSEs, one for each condition (thin / fat) and adaptation phase (*Baseline* and *Adaptation*). The results are shown in Figure 5.2.

A 2x2 repeated measures ANOVA with factors time (*Baseline* / *Adaptation*) and adaptor type (thin / fat) showed no main effect of adaptation $F(1, 19) = 0.82$, $p = 0.376$, $\eta p2 = 0.04$, body type $F(1, 19) = 1.10$, $p = 0.308$, $\eta p^2 = 0.06$, and no interaction, $F(1, 19) = 2.53$, $p = 0.128$, $\eta p2 = 0.12$.

In the thin condition, the body perceived as most average at baseline had BMI = 24.77 (SD = 1.77) and decreased to BMI = 24.08 (SD = 2.07) after adaptation. This difference went in the predicted direction but did not reach significance: $t(19) = 1.72$, $p = 0.051$, $d_z = 0.39$. In the fat condition, the body perceived as most average at baseline had BMI = 24.55 (SD = 1.72), which after adaptation increased slightly to BMI = 24.76 (SD = 1.69) This difference was not significant: $t(19) = 0.65$, $p = 0.26$, $d_z = 0.15$. A direct comparison between Adaptation phase in thin and fat condition (Figure 5.2, *Right panel*) showed a difference in the predicted direction that was marginally significant: $t(19) = 1.73$, p = 0.0496, $dz = 0.39$. I used a one-tailed test for this comparison to determine whether there is a difference in the specific direction predicted by adaptation.

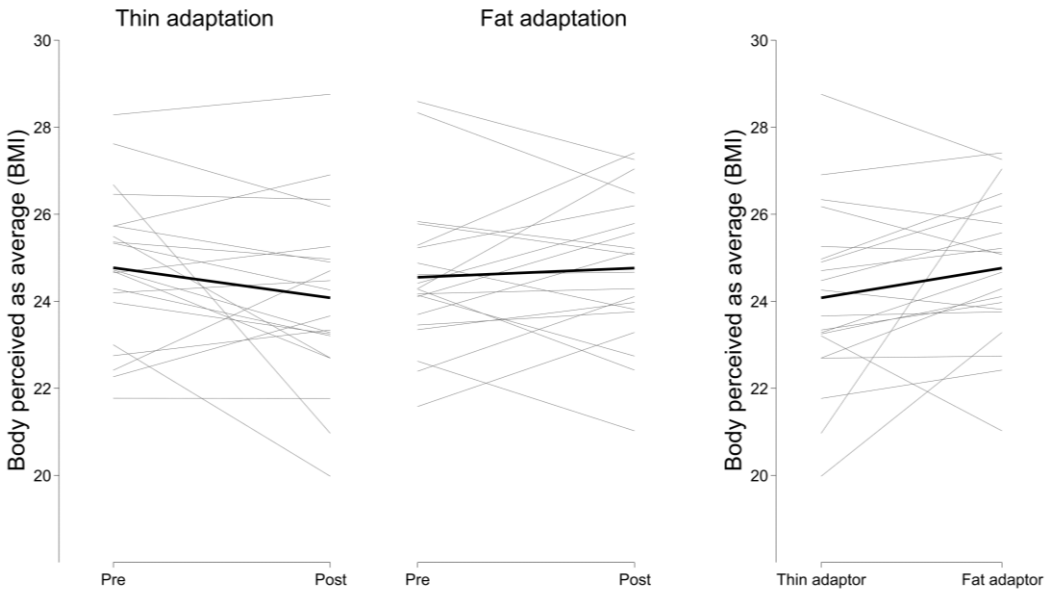

Figure 5.2: Results of Experiment 1 for thin and fat adaptation. The grey lines indicate individual subjects and the mean is shown in black. *Left and middle panels*: there was no effect of adaptation as compared to baseline neither for thin nor fat condition. *Right panel*: Direct comparison between adaptation phase for thin and fat adaptor showed marginally significant effect of adaptation.

These results seem to suggest that, unlike identity or gender, adiposity does not transfer between faces and bodies. To quantify the evidence for the alternative vs null hypothesis, I conducted Bayes factors analysis (Rouder, Speckman, Sun, Morey & Iverson, 2009) using JASP with default parameters (JASP Team, 2017). The results of Bayesian paired t-test directly comparing the Adaptation phase for thin vs fat adaptor provided anecdotal evidence for the alternative hypothesis $BF_{(0, 0.7)} = 1.55$, indicated that the data was 1.55 more likely to be observed under the alternative hypothesis is true. This outcome suggested that the data was inconclusive.

One possible explanation for the lack of clear results was that the adapting stimuli which I chose for Experiment 1 did not induce strong adaptation. In the face adaptation experiment in Chapter 4, I used a different face as an adaptor, i.e. a face looking straight ahead and therefore engaging with the observer. The faces used as adaptors in this experiment were looking away from the observer. It has been shown that people have a robust preference for

direct rather than averted gaze (Lawson, 2015). This raises a possibility that the adaptors in this experiment did not attract enough attention to induce adaptation. Attention has been known to enhance adaptation to low-level features (Rezec, Krekelberg and Dobkins, 2004; Pestilli, Viera & Carrasco, 2007) and previous research suggests that attention may also amplify the higher level aftereffects in face adaptation (Rhodes, Jeffery, Evangelista, Ewing, Peters & Taylor, 2011) and in cross-category adaptation between faces and objects (Javadi & Wee, 2012). I decided to run the next experiment using the same stimuli as adaptors as they proved to work in face adaptation.

5. 3 Experiment 2

In Experiment 2, I used both face adaptors and test bodies with straight orientation. The face stimuli were previously used in face adaptation described in Chapter 2 and the results from this experiment showed that these stimuli can induce facial adiposity aftereffects.

5. 3. 1 Methods

Participants

Twenty female participants (mean age: 22.6, range: 17-36) took part in Experiment 2. All participants gave informed consent and were paid for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli

As adaptors, I used the same face stimuli as in the face adaptation experiment described in Chapter 3. The base thin face (0% morph) served as an adaptor in the thin adaptation condition and the fat base face (100% morph) in the fat adaptation condition (Figure 5.3). As test stimuli, I used the same set of 3D avatars as in Experiment 1. This time however the avatars were positioned facing straight ahead. 2D images were rendered from the avatars.

The stimuli were displayed on the screen with a head cropped out as shown in Figure 5.3. The height of face and body images was matched and equaled approximately 18 cm (20° visual angle).

Figure 5.3: Test stimuli in Experiment 2. A continuum of 89 body shapes was used, ranging from extremely thin (i.e., BMI = 13) to obese (i.e., BMI = 35).

Procedures

The procedures and the analysis in Experiment 2 were identical as in Experiment 1.

5. 3. 2 Results

The results from Experiment 2 are shown in Figure 5.4. In the fat condition, the body perceived as most average at baseline had BMI = 23.77 (1.77), and increased to BMI = 24.54 (SD = 2.01) after adaptation. This difference was significant: $t(19) = 2.91$, $p = 0.009$, $d_z = 0.65$. In the thin condition, the body perceived as most average at baseline had BMI = 23.85 (SD = 1.89), and decreased to 23.50 (SD = 2.03) after adaptation. However, this decrease was not significant: $t(19) = 1.71$, $p = 0.103$, $d_z = 0.38$. However, a direct comparison between adaptation phase in thin and fat condition showed a significant difference in the predicted direction: $t(19) = 4.13$, $p < 0.001$, $dz = 0.92$.

2x2 repeated measures ANOVA with factors adaptation (*Baseline* / *Adaptation*) and adaptor type (thin/fat) showed no main effect of adaptation $F(1,19) = 1.63$, $p = 0.217$, $\eta p^2 = 0.08$. There was however a significant effect of the adaptor type $F(1,19) = 4.92$, $p = 0.039$, ηp^2

= 0.21 and significant interaction between adaptation and adaptor type F(1,19) = 10.89, p = 0.004, ηp^2 = 0.37.

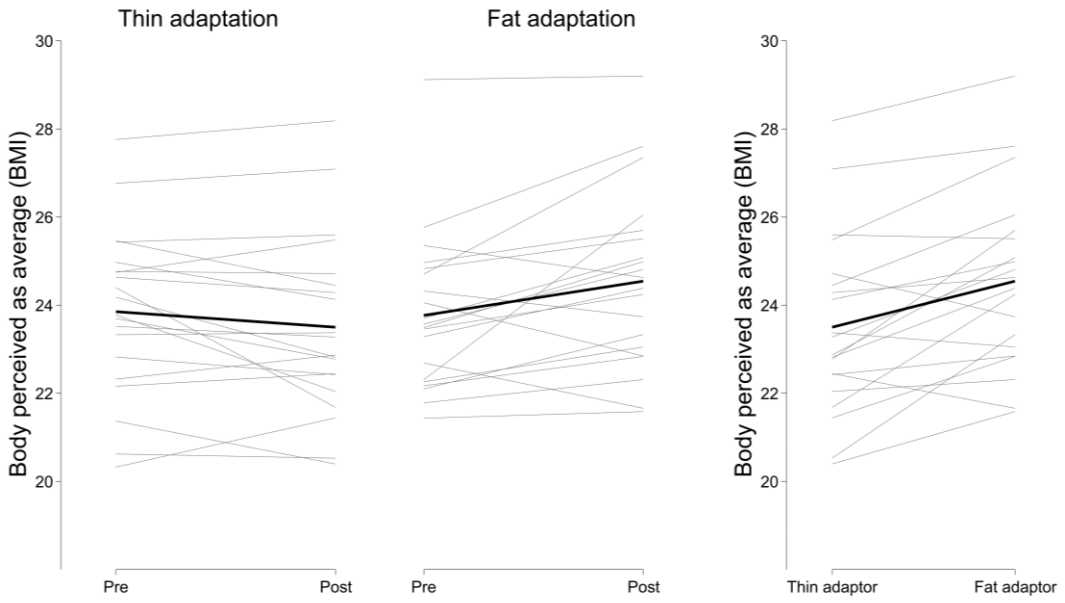

Figure 5.4: Results of Experiment 2. The grey lines indicate individual subjects and the mean is shown in black. *Left panel:* the effect of adaptation as compared to baseline in the thin condition was not significant. *Middle panel*: there was an effect of adaptation as compared to baseline in the fat condition. *Right panel*: Direct comparison between adaptation phase for thin and fat adaptor showed significant effect of adaptation.

Since the only difference between the conditions was the presence of the thin or fat adaptor in the adaptation phase, these results strongly suggest the effect was due to the cross category transfer of the adaptation aftereffects.

The faces used as adaptors in Experiments 1 and 2 may appear extreme or even masculine. This may involve possible risk related to decreased attention, since people are shown to pay more attention to attractive faces (Sui & Liu, 2012) and adaptation aftereffects have been shown to increase with attention (Rhodes, Jeffery, Evangelista, Ewing, Peters & Taylor, 2011). Furthermore, it is not known whether body size aftereffects transfer across genders. However, previous research also showed that extreme faces elicit stronger adaptation,

as long as they are within the range of natural faces (McKone, Jeffery, Boeing, Clifford, & Rhodes, 2014). Although my stimuli may appear extreme, I believe they look realistic for women of very low or high BMI. Face adaptors were designed to match body adaptors in how extreme they were in terms of adiposity. Since in my previous adaptation experiments I used extreme bodies as adaptors, I knew that they induce strong adaptation. Using less extreme adaptors carried a risk of inducing weak or no aftereffects. Therefore, I think that the advantage of using more extreme faces outweighs possible disadvantages.

In the next experiment, I investigated the effect of cross adaptation in the reversed direction, i.e. from bodies to faces.

5. 4 Experiment 3

In Experiment 3, I asked whether adiposity aftereffects transfer from bodies to faces. Participants were adapted to a thin/fat body and made judgements about the adiposity of test faces.

5. 4. 1 Methods

Participants

Twenty female volunteers (mean age: 28.8, range: 22-45) took part in this experiment. All participants gave informed consent. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli and Procedures

The stimuli and the procedures were similar as in Experiment 2, but this time, the bodies were used as adaptors (BMI 35 in fat condition and BMI 13 in thin condition, see Figure 5.3), and faces as test stimuli (a whole range of faces described in Chapter 3, see Figure 4.1). I increased the number of trials in each part to 80 (320 in total).

5. 4. 2 Results and discussion

Results from Experiment 3 are shown in Figure 5.5. In the thin condition, the face perceived as most average was M = 55.76 (SD = 5.84) at baseline, and decreased to M = 50.39 (SD = 7.13) after adaptation. This difference was significant: $t(19) = 4.03$, $p < 0.001$, $d_z = 0.90$. In the fat adaptation, the face perceived as most average at baseline was M = 56.19 (SD = 5.29), and increased to M = 56.75 (SD = 6.77) after adaptation. However, this difference was not significant: $t(19) = 0.47$, $p = 0.32$, $d_z = 0.11$. A t-test directly comparing Adaptation phase in thin and fat condition showed significant difference between conditions: $t(19) = 4.17$, $p < 0.001$, $d_z = 0.93$.

A 2x2 repeated measures ANOVA with factors adaptation (*Baseline* / *Adaptation*) and adaptor type (thin/fat) showed the main effect of adaptation $F(1,19) = 7.79$, $p = 0.012$, $\eta p^2 = 0.29$, and adaptor type, $F(1,19) = 15.86$, $p = 0.001$, $\eta p^2 = 0.45$. Most importantly, there was significant interaction between adaptation and adaptor type $F(1,19) = 10.41$, $p = 0.004$, $\eta p^2 = 0.35$. These results provide further evidence for cross category transfer.

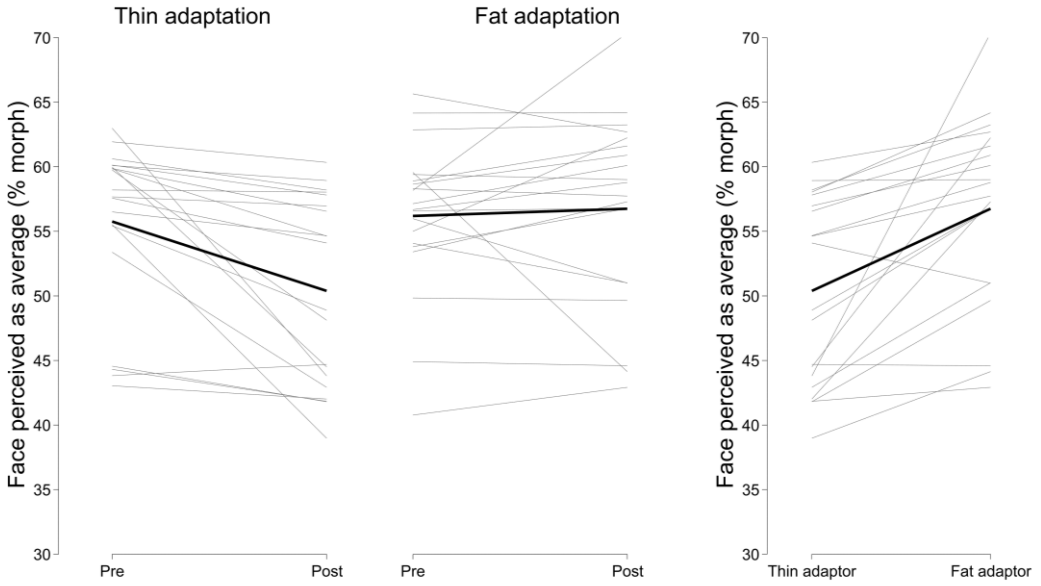

Figure 5.5: Results of Experiment 3. The grey lines indicate individual subjects and the mean is shown in black. *Left panel:* there was a clear effect of adaptation as compared to baseline in the thin condition *Middle panel*: there was no significant effect of adaptation as compared to baseline

in the fat condition. *Right panel*: Direct comparison between adaptation phase for thin and fat adaptor showed clear effect of adaptation.

5. 5 Experiment 4

In Experiment 4, I further investigated transfer of adiposity aftereffects between bodies and body parts by using hands as adapting stimuli. Previous studies has shown that age aftereffects transfer between hands and faces (Lai, Oruç & Barton, 2011). However, no transfer of adaptation aftereffects between faces and hands was found for gender (Kovacs, Zimmer, Bank, Harza, Antal & Vidnyanszky, 2006). Cross-category adaptation between bodies and hands for adiposity has not yet been studied. Here, participants were adapted to a thin/fat hand and asked to make judgements about the adiposity of test bodies.

5. 5. 1 Methods

Participants

Twenty female volunteers (mean age: 25.7, range: 20-39) took part in Experiment 4. All participants gave informed consent. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli and Procedures

The test images of bodies were identical as in Experiments 2. As adaptors, I used images of very thin and fat hand (see Figure 5.6) which I created in Daz studio. The procedures were identical as in Experiment 3.

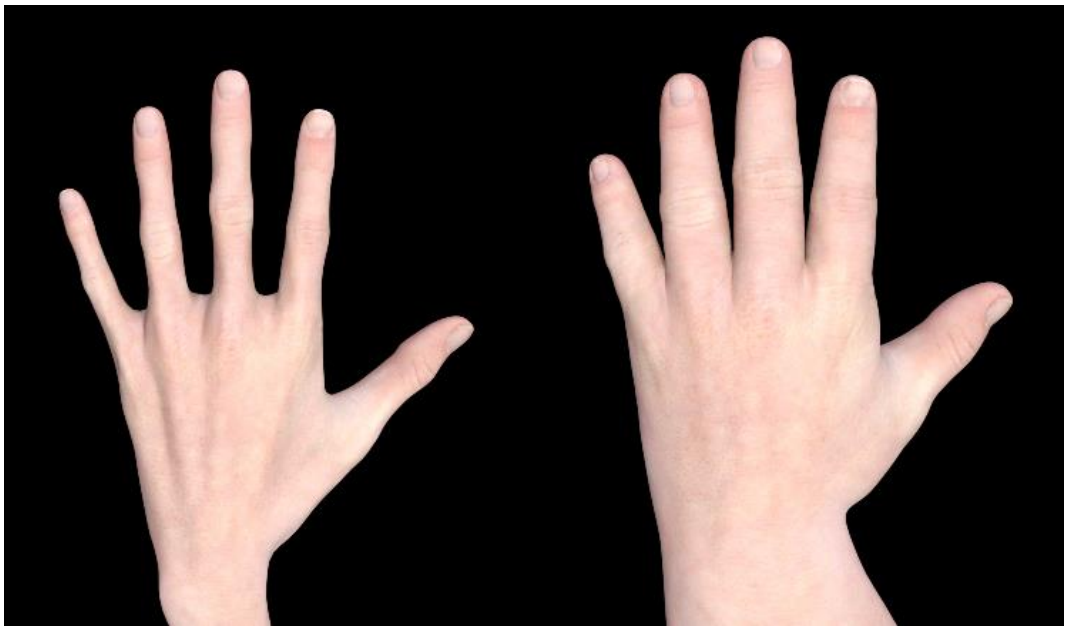

Figure 5.6: Hand adaptors used in Experiment 4.

5. 5. 2 Results

Results from Experiment 4 are shown in Figure 5.7. 2 x 2 repeated measures ANOVA with factors adaptation (*Baseline*/*Adaptation*) and adaptor type (thin/fat) showed no main effect of adaptation $F(1,19) = 0.352$, $p = 0.56$, $\eta p^2 = 0.02$, nor body type, $F(1,19) = 2.707$, $p = 0.116$, $\eta p^2 = 0.13$. There was, however, a significant interaction between adaptation and body type $F(1,19) = 8.951$, $p = 0.007$, $\eta p^2 = 0.32$.

In the thin adaptation condition, the BMI of the body perceived as most average was M = 24.43 (SD = 2.55) at baseline, and decreased to M = 23.92 (SD = 2.58) after adaptation. However, this difference was not significant: $t(19) = 1.60$, $p = 0.125$, $d_z = 0.36$. In the fat adaptation, the BMI of the body perceived as most average at baseline was M = 24.28 (SD = 2.68), and after adaptation increased to M = 25.01 (SD = 2.55). This difference was significant: $t(19) = 3.00$, $p = 0.007$, $d_z = 0.67$. Importantly, the test directly comparing thin and fat adaptation showed significant difference between conditions: $t(19) = 3.26$, $p = 0.004$, $d_z = 0.73$. There was no difference between the conditions at baseline measurement: $t(19) = 0.41$, $p = 0.686$, $d_z = 0.09$, showing that there was no initial bias.

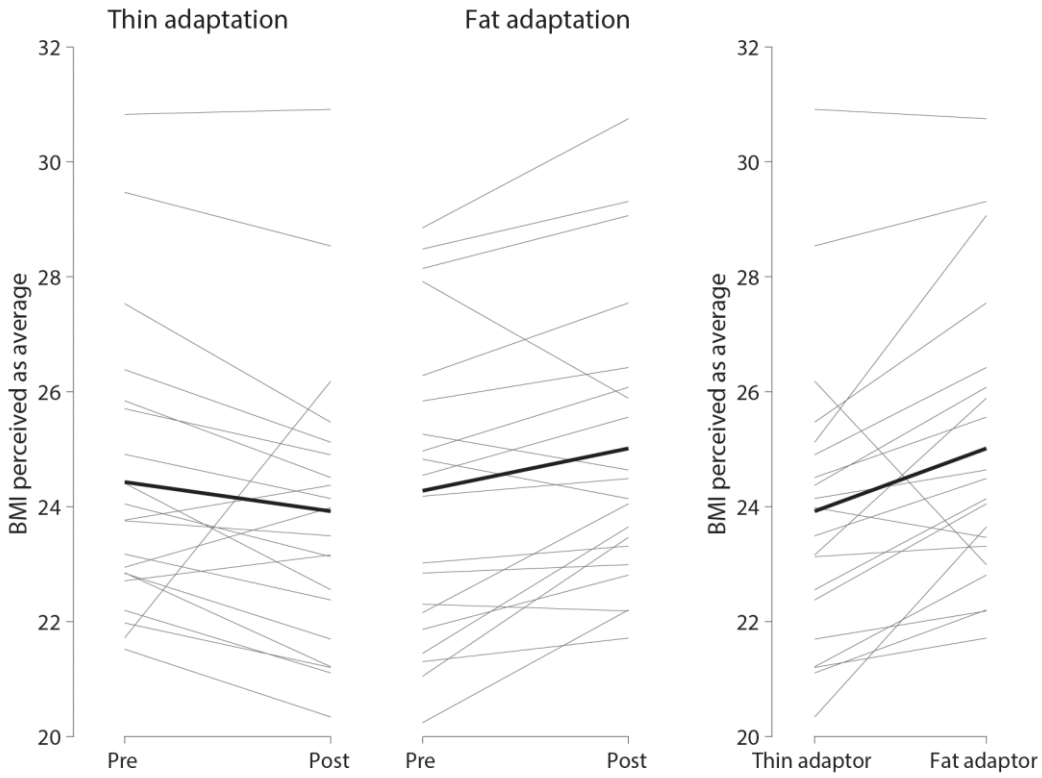

Figure 5.7: Results of Experiment 4. The grey lines indicate individual subjects and the mean is shown in black. *Left panel:* there was no significant effect of adaptation as compared to baseline in the thin condition *Middle panel*: there was a clear effect of adaptation as compared to baseline in the fat condition. *Right panel*: Direct comparison between adaptation phase for thin and fat adaptor showed clear effect of adaptation.

These results provide further evidence that body parts, in this case hands, can serve as adiposity cues and induce visual adaptation to body size that affects representations of entire bodies.

6. General Discussion

Previous studies showed that adaptation aftereffects transfer between bodies and faces for features such as identity and gender. The present study is the first one investigating whether perception of human body size is sensitive to similar cross-category adaptation. In a series of studies, I showed that adiposity aftereffects transfer between full bodies and body parts such as faces and hands.

In media, we are often presented with bodies that are only partially visible, e.g. profile pictures and partial body photographs in magazines. The results reported here suggest that observers do not need to be exposed to the full body images to experience body size aftereffects. While faces and hands may not be the body parts most typically associated with the concept of fatness or thinness, they are the body parts of other people to which we are most often exposed to, since they are least likely to be covered by clothes. My findings suggest that even these body parts can serve as adiposity cues and induce body size adaptation.

The results from these experiments can also be interpreted in the context of the origins of body size adaptation aftereffects. One possible interpretation of body size adaptation could be that adiposity aftereffects result from adaptation to the low level features of the stimuli: the overall size or a specific dimension such as width. In all experiments reported in this chapter, the height of my stimuli was matched but not the width. However, in Experiment 3, the width of both body adaptors was smaller than that of the test faces. If participants were adapted to the width of the adaptors, adaptation should bias perception in the same direction in both conditions. Furthermore, previous studies showed no body size aftereffects after adaptation to wide/narrow rectangles (Hummel et al., 2012). Thus, it seems unlikely that aftereffects occurred simply due to low level adaptation to the dimensions of the stimuli.

The results of this study may also be interpreted in terms of adaptation to a more general, abstract concept rather than a higher level visual representation specific to bodies. Previous studies on cross-category gender adaptation between bodies and gender-specific objects showed mixed results. Ghuman et al. (2010) found no transfer of gender aftereffects between faces and gender-specific objects e.g. shoes, while Javadi and Wee (2012) reported opposite results. However, the strength of the aftereffects reported by Ghuman et al. (2010) depended on the length of the exposure to the adaptor which suggests their perceptual origin. It remains an open question whether body size aftereffects are related to an abstract concept of adiposity.

Finally, adiposity aftereffects may result from higher level sensory adaptation that alters overlapping representations of bodies and faces. Neuroimaging studies show that visual

representations of bodies and faces are coded in adjacent brain areas (Pinsk, DeSimone, Moore, Gross, & Kastner, 2005). I found this last theory the most compelling. First, in this interpretation, body adaptation aftereffects are specific to bodies and body parts, and do not transfer between objects sharing only low-level features, which explains the lack of transfer between bodies and rectangles found by Hummel and colleagues (2012a). Furthermore, it also predicts the lack of transfer between bodies and objects related to the concept of adiposity, as the aftereffects are not a result of a cognitive bias. Instead this theory predicts that neurons in higher-level areas representing bodies, such as the extrastriate body area (Downing, Jiang, Shuman & Kanwisher, 2001), get adapted to a specific body feature during the exposure which results in a temporary shift of the bodily norm. I will discuss the possible underlying mechanisms further in Chapter 8. It is also possible that aftereffects arise at different levels of processing, e.g. at both low and high levels of visual processing. This interpretation is consistent with the fact that aftereffects are the strongest when adaptor and test share low-level features. Since face and body aftereffects show many characteristics of perceptual bias, as discussed above, it seems implausible that these aftereffects arise from cognitive bias alone. However, it seems possible that adaptation may lead to a cognitive bias as a result of perceptual changes.

The effect sizes in my cross-category adaptation experiments were medium: $dz = 0.65$ (Experiment 2), $dz = 0.67$ (Experiment 4) and large: $dz = 0.90$ (Experiment 3) and yet notably smaller than the very large aftereffects in body to body adaptation studies, like the ones discussed in Chapter 2, which were in a range of $dz = 1.34 - 2.07$. This may suggest that adaptation relies in part on the low-level similarity between the test and the adaptor or shared semantic category. However, as showed by the results of the experiments discussed in this chapter, the effect of adaptation is present even when the test and the adapting stimuli belong to different categories. The results of the experiments described here show greater individual differences as compared to the body to body adaptation study in Chapter 2. Not only the magnitude of the aftereffects differed across participants but some of the participants showed an effect in the opposite direction. This may be that the effect of adaptation between categories

is more difficult to elicit. It is possible that adaptation in my cross-category experiments was too short to induce aftereffects in some subjects. Again, as with results from the first study (Chapter 2), my prediction is that individual differences depend in part on attentional factors. Although participants were explicitly instructed not to look away from the adaptors during exposure, I did not control for eye-movements and it is possible that participants did not spent equal amount of time looking at the adapting images. Finally, I cannot reject the possibility that cross-category aftereffects relies on more than one mechanism, i.e. a combination of sensory adaptation and cognitive bias and some participants are more prone to one but not the other. I will discuss this further in Chapter 8.

In the next chapter, I will discuss experiments investigating whether body size adaptation can transfer beyond visual perception.

Chapter 6: Beyond body image - cross-modal transfer of body size aftereffects.

6. 1 Introduction

The aim of this thesis is to investigate how looking at other bodies influences body representations. In the experiments described in the previous chapters, I focused on the question how visual adaptation can affect visual perception of the body. I was particularly interested whether adaptation can affect the conscious body image. However, the knowledge of the size of the body and body parts is important not only for body image but also plays a role in many tasks e.g. implicit knowledge of the distance between the ears is important for interpreting auditory signals (Aslin, Pisoni & Jusczyk, 1983) and information about the distance between the eyes affects depth perception in vision (Banks, 1988). Likewise, information about the size of the body parts contributes to determining the relative locations of body parts when using proprioception (Longo & Haggard, 2010). The implicit model of body size also mediates metric properties of tactile stimuli (Longo, Azanon, & Haggard, 2010).

It has been shown that this implicit model of body size can be shaped by visual experience. Taylor-Clarke, Jacobsen & Haggard (2004) showed that manipulation of the visual experience of one's own body can affect metric properties of perceived touch. In this study, participants underwent visual training, during which they viewed their hand as reduced and their forearm as increased. Afterwards, they performed a tactile discrimination task in which they had to discriminate between tactile distances applied to the arm and to the hand. The results showed that this visual training affected perception of the tactile distances. The authors suggest that judging tactile distances requires a rescaling of the tactile inputs according to the visually specified size of body parts to achieve tactile object constancy. Furthermore, this rescaling seems to be adaptive and driven by visual experience of our own bodies. These results show that visual experience with bodies shapes more than visual representations such

as conscious body image. The question that emerges now is whether visual adaptation to body size can affect other types of body representations, e.g. the model of body size underlying tactile perception.

In the previous chapter, I discussed the results of a series of experiments showing that body size aftereffects can transfer between visual stimuli belonging to different categories such as whole bodies and body parts. These results raise the question about the overlap between the adapting and test stimuli that is necessary for adaptation to occur. How similar does the adapting stimulus need to be to the test to still evoke aftereffects? It had been demonstrated that cross-category aftereffects transfer between stimuli that that have different low level properties but are linked on the abstract level, e.g. bodies and faces (Ghuman et al., 2010), faces and objects (Javadi & Wee, 2012), or industrial and natural scenes (Greene & Oliva, 2010). All these examples, however, require both adaptor and test stimuli to be visually presented. Can adaptation aftereffects transfer between different modalities?

In this chapter, I present two experiments investigating whether adaptation to body size can transfer between stimuli belonging to different modalities. The cross-modal adaptation aftereffects have been previously demonstrated mostly for low-level features: Krystallidou and Thompson (2016) have found transfer of orientation aftereffects between vision and touch, and several studies have reported cross-modal transfer of motion aftereffects in vision, audition, touch and vestibular perception (Kitagawa & Ichihara, 2002; Cuturi & ManNeilage 2014; Konkle, Wang, Hayward & Moore; 2009). For example, Kitagawa and Ichihara (2002) showed that visual cues affected auditory motion aftereffects. In this study, adaptation to a visual stimulus moving in depth (a square changing-size) biased the perception of a steady sound which was now perceived as changing loudness in the opposite direction. Cuturi and ManNeilage (2014) demonstrated that visual adaptation to a rapidly expanding or contracting optic flow pattern biased vestibular perception of self-motion in the direction opposite to the adapting stimulus, i.e. physical movement in the same direction as the visually simulated self-motion was required to cancel the aftereffects. Finally, Konkle, Wang, Hayward and Moore (2009) found that motion aftereffects transfer between vision and touch: after

tactile adaptation during which participants received repeated downward-moving tactile stimulation to their finger, they judged an oscillating visual grating to be moving upwards. Similarly, repeated exposure to visual motion produced a tactile motion aftereffect.

Based on these results, Konkle & Moore (2009) suggested that adaptation affects the stimulus at all levels of processing: "any area or circuit that processes a stimulus is changed by that stimulus and that these dynamics are a functional property of areas throughout the system" (p. 480). As motion perception is thought to be a relatively low-level process, the transfer of motion aftereffects has been interpreted as support for the hypothesis that sensory processing even at its early stages show cross-modal interactions which can result in changes in perception. However, the evidence for cross-modal adaptation for complex, "high-level" stimuli is scarce. Matsumiya (2013) showed that facial expression aftereffects transfer from touch to vision. In his study, participants were first adapted to a facial expression (happy or sad) of a 3D mask of a face, which they explored haptically but did not see. Then, participants judged facial expressions of visual images of faces. The results showed that after haptic adaptation to a sad face the visually presented faces were judged as more happy and vice versa, suggesting that facial-expression aftereffects transfer between vision and touch. Importantly, these aftereffects biased perception away from the adapting stimulus, i.e. showed negative direction typical for sensory adaptation, which rules out the effect of priming.

Other studies investigating cross-modal transfer of higher-level aftereffects report opposite findings. Fox and Barton (2007) found no transfer of adaptation aftereffects between emotional facial expressions and emotions expressed vocally through neutral sentence read with emotional prosody. Studies investigating transfer of aftereffects between faces and voices for gender (Schweinberger, Casper, Hauthal, Kaufmann, Kawahara, Kloth, Robertson, Simpson and Zäske, 2008) and age (Lai, Oruç and Burton, 2012) also showed no cross-modal adaptation.

The question whether body size adaptation aftereffects generalize to other types of body representations in other modalities has not been answered before. Here, I investigated

whether body size aftereffects transfer between: vision and passive touch (Experiment 1) and between vision and haptics (Experiment 2).

In Experiment 1, I investigated whether visual adaptation to a narrow or a wide hand of another person affects participants' perception of tactile distances on the hand. Previous research showed that visual model of the body underlie tactile size perception: modifying the visually perceived size of body parts changes the perceived size of objects touching the skin (Taylor-Clarke, Jacobsen & Haggard, 2004). Thus, in Experiment 1, I asked whether visual adaptation to an image of another person's hand affects performance in a tactile distance discrimination task.

In Experiment 2, I asked whether body size aftereffects can transfer between vision and haptics during active exploration of an object, using a design very similar to the one used by Matsumiya (2013). Previous studies have shown that cortical areas dedicated to visual processing of faces and bodies, such as the fusiform gyrus and the lateral occipito-temporal cortex, can also show category-selective responses when the preferred stimuli are haptically explored (Kitada, Johnsrude, Kochiyama & Lederman, 2009; Costantini, Urgesi, Galati, Romani and Aglioti, 2011). These results suggest the existence of multimodal body representations in the occipito-temporal cortex which are activated during either visual and haptic perception. Therefore, in Experiment 2, I investigated whether haptic exploration of a body can induce aftereffects in visual perception of bodies.

6. 2 Experiment 1: Visual adaptation and tactile anisotropy

In Experiment 1, I tested the effect of visual adaptation on passive touch. Previous research showed that visually altering the size of body parts produces corresponding changes in the perceived tactile distances on the skin (Taylor-Clarke et al. 2004). Here, I made use of an effect known as an anisotropy in perceived tactile distance (Longo & Haggard, 2011; Calzolari, Azañón, Danvers, Vallar & Longo, 2017). Longo and Haggard (2011) showed that when participants judged which of two tactile distances on the hand felt larger, the distances that were aligned with the mediolateral axis (across the hand) were consistently perceived as

larger than the distances aligned with the proximodistal axis (along the hand). The authors argue that this effect reveals underlying distortions in body representation: in the body model mediating touch, the hand is represented as wider and more squat than it really is. This explanation is consistent with the results of other studies using proprioceptive judgments and metric assessment of the hand dimensions (Longo & Haggard, 2010; Longo & Haggard, 2012).

Here, I made use of the anisotropy effect to investigate whether this mental body model i.e. a body representation underlying perception of touch is affected by visual adaptation. On each trial, two pairs of touches defining different tactile distances were applied sequentially to the hand, one pair along and the other across the hand. Participants made two-alternative forced choice (2AFC) judgments of which distance felt larger. I used the method of constant stimuli to estimate biases in the perception of size as a function of orientation (across/along) in three adaptation conditions. I followed the methods used in previous studies (Longo & Haggard, 2012; Calzolari et al., 2017) to make sure that I can replicate the anisotropy effect found previously so that any lack of adaptation is not due to different methodology. The 2AFC task is designed to measure difference in perception of two stimuli presented in the same trial under two different conditions, in this case across and along the hand, when the effect is expected for one but not the other. On each trial participants are forced to choose between one of the stimuli, making the same judgement (here "which distance was longer"), which reveals the bias, in this case the bias to perceive the distance across the hand as longer. The method of constant stimuli uses a predefined, limited set of stimuli that are presented repeatedly over many trials (Kingdom & Prince, 2010). Thus, this method is different than the adaptive procedure I used in previous experiments, in which the stimulus on each trial is selected from a wide range of possible stimuli, based on participants performance. Here, the range of possible distances was already limited by the dimensions of the hand. Furthermore, selecting several predefined levels of stimulation makes it easier to construct the physical stimuli used to apply touches on the hand and facilitates data collection.

Participants performed the task before and after adaptation to very slender / fat hands. I predicted that exposure to a thin hand, would produce negative aftereffects in the way the

hand is represented (similar to visual aftereffects), therefore, after thin adaptation the hand should be represented as wider and more squat which will make the effect of tactile anisotropy even stronger. I expected Fat adaptation to have the opposite effect, causing the hand to be represented as more slender, due to the negative aftereffect, which would reduce the tactile anisotropy.

6. 2. 1 Methods

Participants

Nineteen participants (mean age: 28.7, SD: 9.3, range: 49-18; 9 females) took part in Experiment 1. Previous studies measuring anisotropy showed effect sizes of d = 1.5 and d = 2.2 (Calzolari et al., 2017). Power analysis using G*Power 3.1 and taking the smaller of these values, indicated that a sample of 5 participants was required to replicate this result. However, in this study I was not looking at the effect of anisotropy but at the change between adaptation conditions. In the study by Calzolari et al. (2017) participants were adapted to tactile distances and the resulting change in anisotropy was dz = 2.44 and dz = 1.59. G*Power analysis indicated that a sample of 6 participants was required for the smaller of this values. Since I was testing an adaptation between modalities I suspected the effect size to be smaller and I used a bigger sample. Twenty four participants were scheduled for testing however due to technical issues during data collection, only nineteen participants finished the entire session and provided a complete data set for further analysis. All participants gave informed consent and were paid for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli

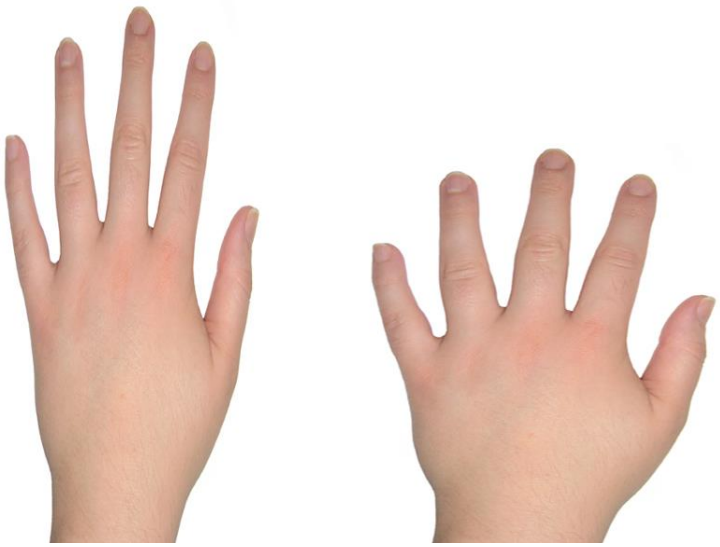

Figure 6.1: Adaptors in Experiment 1. In the thin adaptation condition, the image of a hand was stretched vertically to depict a narrow hand (left). In the fat adaptation condition the image was stretched horizontally to depict a squat hand (right).

As visual adaptors, I used two images of a dorsal side of a left hand taken from a previous study by Longo & Haggard (2012). The images have been stretched either vertically to depict a narrow hand (Thin adaptation condition, Figure 6.1, left) or horizontally to depict a squat hand (Fat adaptation condition, Figure 6.1, right)[4]. The narrow hand had a shape index (Napier, 1980) of 40, whereas the wide hand had a shape index of 90. The shape index was calculated as SI = 100×(width/length), with the width quantified as the distance between the knuckles of the index and little fingers, and the length as the length (knuckle-to-tip) of the middle finger. Female participants were adapted to female hands (depicted in Figure 6.1), whereas male participants were adapted to male hands. The height of the thin adaptor was approximately 19 cm (21° 30' visual angle) and the fat adaptor was 14 cm (16° visual angle).

[4] One advantage of using these stimuli, was that "thin" and "fat" hand images were distorted by an equal, quantifiable amount and therefore were expected to induce equally strong aftereffects in opposite directions. On the other hand, it could be argued that they look too unrealistic to induce adaptation. However, body images stretched by an equal amount in opposite directions have been commonly used in previous adaptation studies and proved to induce aftereffects (e.g. Winkler & Rhodes, 2005; Hummel et al. 2012a, Hummel et al. 2012b). Moreover, previous studies found that faces distorted in clearly manipulated and unrealistic way induced adaptation aftereffects (Webster & MacLin, 1999; Rhodes et al., 2003; Watson & Clifford, 2003).

In the tactile discrimination task, stimuli were pairs of pointed wooden rods mounted on a foamboard and separated by 2, 3, or 4 cm, similar to those used in previous studies (Longo & Haggard, 2011; Calzolari, Azañón, Danvers, Vallar & Longo, 2017). The tip of each post was pointed but not sharp so the stimulation was not painful.

Procedures

Participants were seated in front of a computer screen with their left hand rested on a table. An occluding board was placed between the participant and the experimenter in such a way that participants were not able to see the stimulation applied to their hand. Participants performed a tactile distance discrimination task in three adaptation conditions: *Baseline, Thin adaptation* and *Fat adaptation*.

In the Baseline condition, on each trial participant received two tactile stimulations delivered manually by the experimenter: one across and one along the hand, each consisting of two simultaneous touches either 2, 3, or 4 cm apart. These three different lengths of stimuli were delivered to the hand in five possible across/ along combinations: 2 / 4 cm, 2 / 3 cm, 2 / 2 cm, 3 / 2 cm, 4 / 2 cm. The stimulation was applied approximately in the center of the dorsum. The duration of each touch was approximately one second, with an interstimulus interval of approximately one second. The order of across/along stimulation was randomized and counterbalanced. Participants were asked to verbally indicate which stimulus felt longer (as in having the two rods farther apart): the first or the second. The response mode (first/second) was made orthogonal to the tested dimension (across/along) in order to minimize the probability that the results reflected the response bias. After the response a new trial began. Each across/along ratio was presented 14 times (7 times the stimulus was first applied across the hand and 7 times along the hand) in random order, which resulted in 70 trials per condition (210 in total) divided into 2 blocks of 35 trials with a short break between the blocks.

In the adaptation condition, at the beginning of each block participants first passively view an image of a slender/fat hand for 1 minute. After that participants performed the tactile distance discrimination task again. The trial structure was the same as in Baseline, with an

addition of a visual adaptor presented again for 3 seconds and followed by a fixation cross. After this brief top-up adaptation, the tactile stimulation was delivered by the experimenter as in Baseline condition. After a 10-minute break, the procedures were repeated using an opposite adaptor. The order of thin/fat adaptation was counterbalanced across participants.

Analysis

First, in each adaptation condition, I calculated the proportion of trials in which the test stimulus delivered along the hand was judged as longer and analyzed it as a function of the ratio of the length of the across/along stimulus (1/2, 2/3, 1, 3/2, or 2). The ratios were transformed logarithmically, to produce a symmetrical distribution around the point of actual equality (ratio = 1). Cumulative Gaussian function was fitted to each participant's data using maximum likelihood in Palamedes toolbox in MATLAB (Prins & Kingdom, 2018). From this function, I determined a PSE in which stimulation across and along the hand was perceived as equal. Thus, three PSEs per participants were obtained for statistical analysis.

PSE values smaller than 1 indicated a general tendency to perceive a distance delivered across the hand as being longer than those delivered along the hand, whereas PSE values larger than 1 indicated the opposite. Longo and Haggard (2011) related PSE to the underlying representation of hand shape in a following way: if there is no distortion of hand shape, PSEs should equal 1, indicating that stimulus orientation does not bias perceived size. If, however, the hand is represented as being longer and more slender than it is, stimuli across the hand would have to be larger than those along the hand for the two to be perceived as equal, resulting in PSEs greater than 1. Conversely, if the hand is represented as wider and more squat than it really is, stimuli along the hand would have to be larger than those across the hand for the two to be perceived as equal, and PSEs less than 1 would be expected. Following this logic, I expected that exposure to a thin hand, would produce negative aftereffects in the way the hand is represented (similar to visual aftereffects), therefore, after thin adaptation the hand should be represented as wider and more squat and PSE should

decrease as compared to Baseline. I expected fat adaptation to have the opposite effect, causing the hand to be represented as more slender and PSE to increase.

For each participant in each condition, I also calculated the goodness of fit (R-squared) of the psychometric function. One participant showed very low R-squared value in the baseline condition (0.31), and was excluded from the analysis. For the remaining 18 participants, the average R-squared for the *Baseline* condition was 0.94 (range = 0.78–1), for the *Thin adaptation* condition was 0.92 (range = 0.76–1), and for the *Fat adaptation* condition was 0.94 (range = 0.60–1), indicating good fit to the data

6. 2. 2 Results and discussion

The results are shown in Figure 6.2. I first looked whether anisotropy effect was present in my data. The mean PSE in the *Baseline* condition was 0.75 (range 0.31-1.11), significantly less than 1, $t(17) = 4.04$, $p < 0.001$, $d = 0.95$. Similarly, mean PSE in the *Thin adaptation* condition was 0.78 (range 0.31-1.10), $t(17) = 3.48$, $p = 0.003$, $d = 0.82$ and mean PSE in the *Fat adaptation* condition was 0.74 (range 0.42-1.00), significantly less than 1, $t(17) = 5.35$, $p < 0.001$, $d = 1.26$. Thus, the anisotropy effect was found in all conditions. These results replicated previous finding that people perceive touch along the hand as longer than across (Longo & Haggard, 2011; Calzolari, Azañón, Danvers, Vallar & Longo, 2017).

My main experimental question concerned the shift in PSEs between the adaptation conditions. To test whether anisotropy was affected by adaptation manipulation, I conducted a repeated measures ANOVA with factor adaptation condition (*Baseline*, *Thin adaptation*, *Fat adaptation*). The results revealed no effect of adaptation condition $F(2, 34) = 1.10$, $p = 0.353$, $\eta p^2 = 0.06$, showing that anisotropy effect was not influenced by adaptation, suggesting that aftereffects do not transfer between vision and touch. I conducted another ANOVA on the slopes of the psychometric functions and found no difference between the conditions: $F(2, 34) = 0.52$, $p = 0.597$, $\eta p^2 = 0.03$, showing that adaptation did not affect participants' sensitivity.

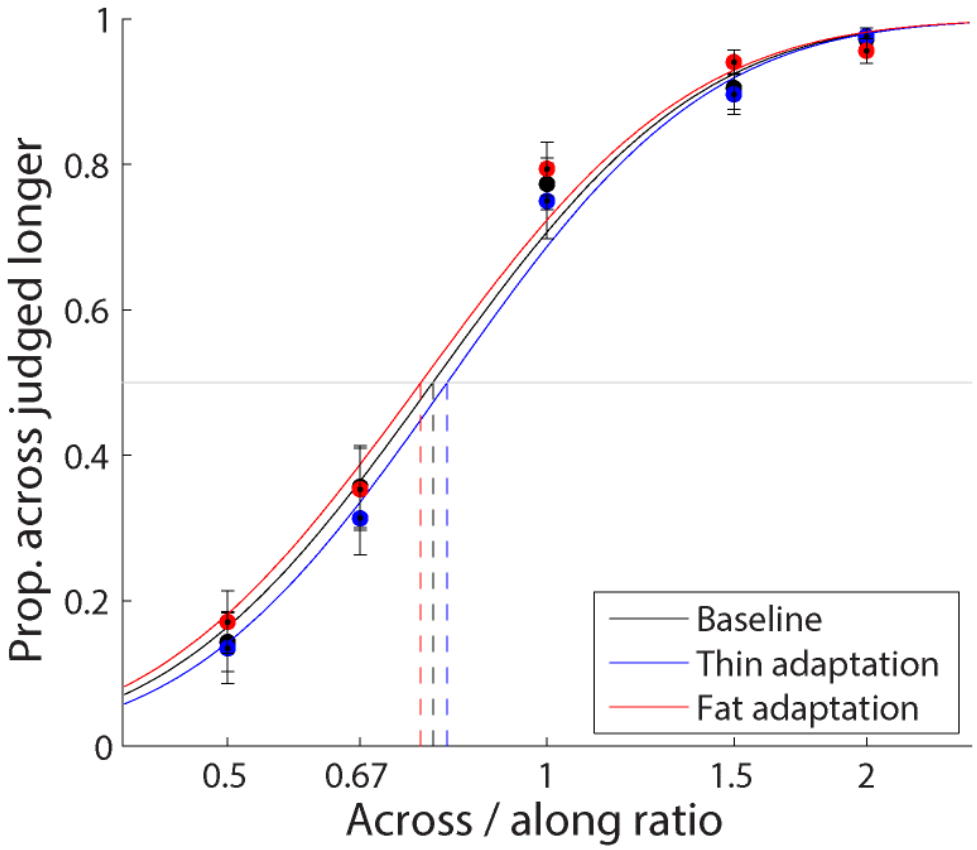

Figure 6.2: Results of Experiment 1. Error bars represent the standard error of the mean. Curves are cumulative Gaussian functions fit with maximum likelihood. Vertical lines represent points of subjective equality

To find evidence for the lack of transfer (i.e. support for the null hypothesis), I conducted Bayes Factors analysis using JASP with a default settings (JASP Team, 2017) and a directional predictions (half Cauchy prior). A Bayesian t-test confirmed the lack of transfer both between *Baseline* and *Thin adaptation*: $BF_{(0,\ 0.7)} = 6.71$, and between *Baseline* and *Fat adaptation*: $BF_{(0,\ 0.7)} = 6.61$. Thus, the data provide evidence against the effect of visual adaptation on perceived tactile anisotropy on the hand.

Taylor-Clarke et al. (2004) showed that altering the visual representation of participants own hand and forearm affects perceived distance between two touches. Here, I found that adaptation to an image of a thin or fat hand of another person does not affect perceived tactile distance. These results suggests that looking at other person's hand does not

modulate the mental model of body size in the same way as the visual alteration of one's own body. In addition, in the study by Taylor-Clarke et al. (2004) the visually altered image of participant's hand and forearm was projected onto a table close to the location of participant's physical hand and forearm. It remains an open question whether adaptation to the altered version of participants own hand presented on a screen away from the physical location of the actual hand would affect perceived tactile anisotropy on this hand.

6. 3 Experiment 2: Haptics to vision

In Experiment 1, I investigated the effect of visual adaptation on a tactile distance discrimination task but found no transfer of aftereffects between vision and passive touch. In Experiment 2, I asked whether body size aftereffects can transfer between vision and haptics during active exploration of an object. Previous studies (Kitada et al., 2009; Costantini et al., 2011) have shown that cortical areas dedicated to visual processing of bodies show category-selective responses when body parts are haptically explored suggesting the existence of multimodal body representations in the occipito-temporal cortex which are activated during either visual and haptic perception.

Here, I investigated whether haptic exploration of a 3D figure depicting a very thin or fat body affects visual perception of bodies. I used a similar experimental design to the one used by Matsumiya (2013) who reported transfer of facial-expression aftereffects between haptics and vision. Participants first haptically explored a 3D figures of bodies and then made judgements about adiposity of visually presented bodies.

6. 3. 1 Methods

Participants

Due to the nature of my stimuli (depicting female bodies), in Experiment 2 I restricted my sample to female participants. Thirty participants (mean age: 27.2, SD: 11.5, range: 20 - 68) gave informed consent and were paid for their participation. The procedures were

approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Stimuli

As test stimuli, I used a set of images of female bodies which differed in BMI (ranging from 13 to 35) rendered from the 3D avatars used in all previously described body adaptation studies presented in this thesis. The bodies were presented facing straight ahead (Figure 6.2). The same images were previously used in Experiment 2 and 4 described in Chapter 5 but here they were displayed in full, including the head.

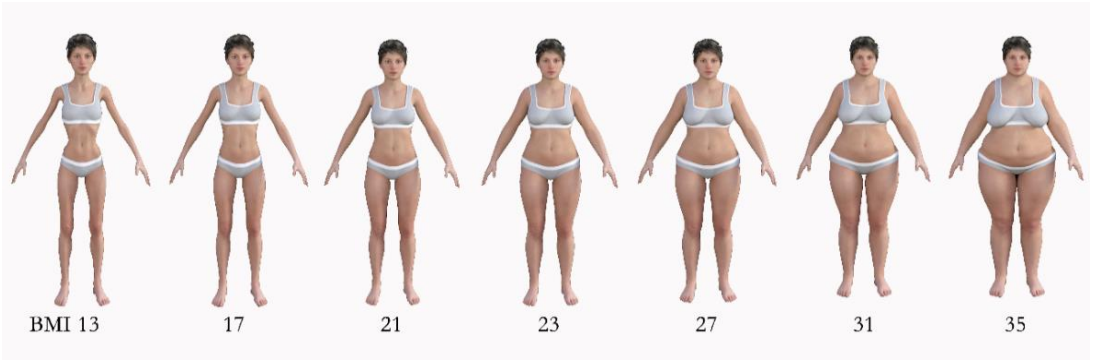

Figure 6.2: Examples of the test stimuli used in Experiment 2.

As tactile adaptors, I used two plastic figures: a thin and a fat body (Figure 6.3) which I created using a 3D printer (Ultimaker 2+, Ultimaker B.V.) from the same 3D avatars which served as a base for the test images. The thin adaptor was printed based on a model with a BMI = 13, while the fat adaptor was printed from a BMI 35 model. Thus, the identity of the test and adapting body was the same. To prepare the models for printing, I used Meshmixer (Autodesk Inc.) and Cura (Ultimaker B.V.) software. The height of each figure was 15 cm.

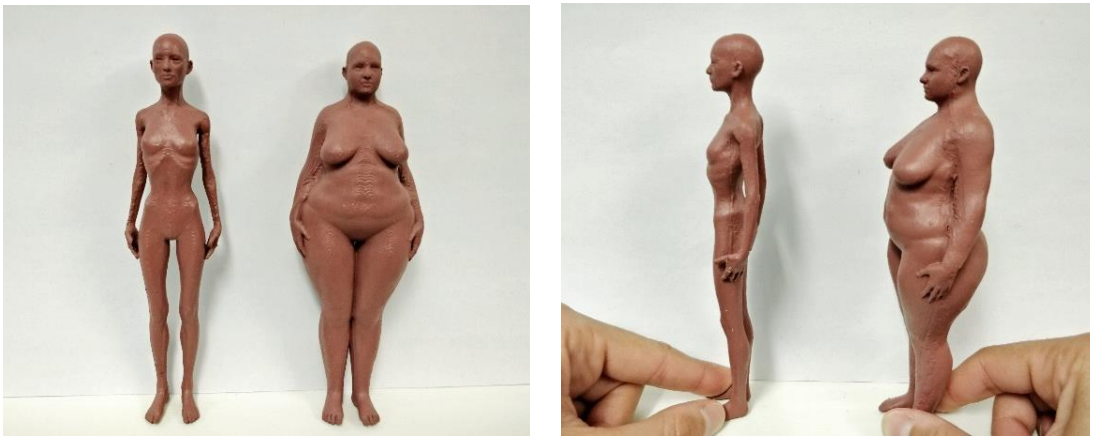

Figure 6.3: Stimuli used as adaptors in Experiment 2 presented facing straight (left panel) or from the side (right panel). The figures were created using a 3D printer from the 3D models used in my previous experiments. The thin adaptor was printed based on a model with a BMI = 13, while the fat adaptor was printed from a BMI 35 model.

Procedures

The procedures were very similar to the experiments described in Chapter 5. This time, however, as adaptors I used 3D figures of a thin and a fat body. An occluding board was placed under the screen and above participants' hands, while another occluding board separated the participants from the experimenter collecting the data to make sure that participants did not see the adapting figures at any point (Figure 6.4). Participants were sitting approximately 50 cm from the screen with head movements unrestricted. The visual task was presented using Psychtoolbox (Brainard, 1997), running on MATLAB (Mathworks, Natick, MA). The images were presented in the centre of a 24 inches screen, on a black background. The height of each image was approximately 18 cm (20° visual angle). The responses were made using labelled keyboard keys under the occluding board.

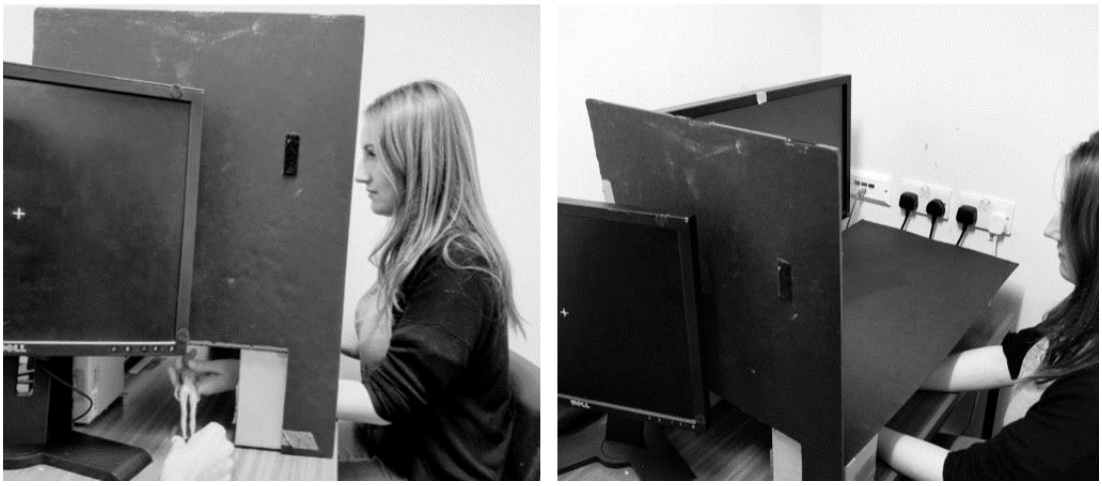

Figure 6.4: The setup used in Experiment 2. *Left panel:* the participant is handed the adapting figure under the occluding board. Right panel: the participants haptically explore the adaptor, while looking at the fixation on the screen.

The experiment consisted of four parts: the *Baseline* and *Adaptation* phase, each repeated twice, once with a thin and once with a fat adaptor. There were 72 trials in each part (288 in total) and two PSE's were calculated based on 36 trials each using QUEST (Watson, 1983). In the Baseline phase, participants judged visual images of bodies from the BMI spectrum 13-35, on each trial answering the question: *Is this body thinner or fatter than average?* Each trial began with a blank screen (250-ms) followed by the test body (1000-ms). Then, the screen remained blank until the response was made. A black cross (500-ms) indicated the end of the trial.

In the Adaptation phase, during the initial adaptation participants haptically explored a 3D figure of either a very thin or a fat body (see Figure 6.3) for 2 minutes while looking at the fixation cross presented on the screen. The occluding board, placed above participants' hands, prevented them from looking at the adapting figures. Then, the experimenter removed the adapting figure and participants performed a similar task as in the Baseline phase with the addition of a 'top-up' adaptation: on each trial participants were handed the adapting figure to explore again for 6 seconds, while the fixation cross was presented on the screen, to ensure that adaptation was sustained during the entire session. After the fixation cross disappeared,

the experimenter removed the figure and a blank screen was presented (1000-ms), followed by the visual test stimulus (1000-ms). Then, the screen remained blank until the response was made. Because in the Adaptation phase the task alternated between tactile and visual stimuli, to learn the trial structure participants performed 8 practice trials before receiving any adaptation. During practice, a neutral figure was used instead of an adaptor.

The procedure was repeated for the adaptor from the opposite side of the thin-fat spectrum with a 10-minutes break in-between to allow the effect of adaptation to wear off. The order of thin/fat adaptation was counterbalanced across participants.

6. 3. 2 Results and discussion

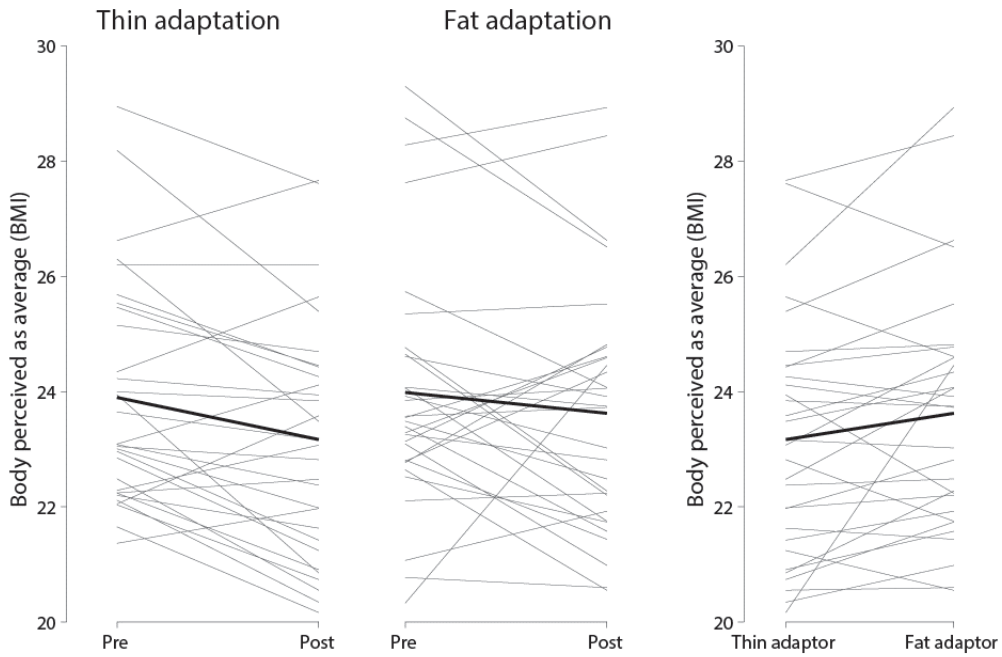

Figure 6.5: Results of Experiment 2 for thin and fat adaptation. The grey lines indicate individual subjects and the mean is shown in black. *Left panel:* there was an effect of adaptation as compared to baseline in the thin adaptation condition. *Middle panels*: there was no effect of adaptation as compared to baseline in the fat adaptation condition. *Right panel*: Direct comparison between adaptation phase for thin and fat adaptor showed marginally significant effect of adaptation.

In each adaptor type condition (thin / fat), two 50% thresholds (PSEs) per adaptation phase (Baseline / Adaptation) were calculated using QUEST to estimate the BMI at which participants were equally likely to respond thinner or fatter. These two thresholds were then averaged, resulting in 4 PSEs, one for each condition (thin / fat) and adaptation phase (Baseline and Adaptation). The results are shown in Figure 6.5.

In the thin adaptation condition, the body perceived as most average at baseline had BMI = 23.90 (SD = 1.97) and decreased to BMI = 23.17 (SD = 2.06) after adaptation. This difference went in the predicted direction and was significant: $t(29) = 3.31$, $p = 0.002$, $d_z = 0.61$. In the fat adaptation condition, the body perceived as most average at baseline had BMI = 23.98 (SD = 2.17), which after adaptation also decreased slightly to BMI = 23.62 (SD = 2.13). This difference went in the direction opposite to my predictions and was not significant: $t(29) = 1.22$, $p = 0.234$, $d_z = 0.22$. A direct comparison between Adaptation phase in the thin and fat condition (Figure 6.5, Right panel) showed a difference in the predicted direction that was marginally significant: $t(29) = 2.11$, $p = 0.044$, $d_z = 0.36$. There was no significant difference between the Baseline phase in the thin and fat condition: $t(29) = 0.37$, $p = 0.716$, $d_z = 0.07$.

A 2x2 repeated measures ANOVA with factors time (Baseline / Adaptation) and adaptor type (thin / fat) showed the main effect of adaptation $F(1, 29) = 6.01$, $p = 0.02$, $\eta_p^2 = 0.17$, but no effect of body type $F(1, 29) = 2.30$, $p = 0.141$, $\eta_p^2 = 0.07$, and no interaction, $F(1, 29) = 1.82$, $p = 0.188$, $\eta_p^2 = 0.059$. To quantify the evidence for and against the interaction, I conducted Bayes factors analysis (Rouder, Speckman, Sun, Morey & Iverson, 2009). The results of Bayesian repeated measures ANOVA, conducted in JASP using default parameters, provided evidence against the interaction between adaptation and body type conditions: BF = 0.213.

Unlike in the visual adaptation experiments, I found a clear effect in the thin but not in the fat adaptation condition. What is more, the difference between the baseline and the fat adaptation went in the same direction as in the thin adaptation condition, contrary to my expectations. This the lack of interaction may suggests that the effect was not due to the

exposure to the thin or fat adaptor. Alternatively, it can be argued that the thin adaptor induced adiposity aftereffects whereas the fat adaptor did not. It is possible that while judging the adiposity level of a haptically explored body people rely on other cues than body size and shape, e.g. the firmness vs softness. In the common view, thin bodies are trim and firm while fat bodies are soft and jiggly. Since the stimuli in haptic adaptation were made of firm plastic it is possible that the fat adaptor induced conflicting adiposity cues i.e. the shape of a larger body but paired with firmness that implicitly activated association with a firmer body. Therefore, it is possible that the fat adaptor was perceived as less extreme, and served as a weaker adaptor. Although when verbally briefed at the end of experiment participants explicitly admitted that they perceived the fat adaptor to be fat, it may be that the implicit association between firm and thin affected the results. One way of addressing this issue would be to test whether adaptation to a figure of a fat body made of a softer material is more effective in inducing aftereffects in visually presented bodies.

Moreover, it is not clear how accurate the participants were in recognizing body size and shape based on haptic exploration of the adaptors. It has been well demonstrated that people can recognize haptically explored faces and facial expressions (Kilgour & Lederman, 2002, 2006; Dopjans, Bülthoff, & Wallraven, 2012). However, to my knowledge, there are no studies showing how accurately people can recognize body size and shape from haptic exploration alone. Another question, which I would like to explore in my future research, is whether body size adaptation to a haptically explored body can affect tactile perception of other haptically explored bodies.

6. 4. General discussion

In this chapter, I discussed two experiments investigating whether body size aftereffects can transfer between modalities. In Experiment 1, I asked whether visual adaptation to a thin or fat hand of another person can affect anisotropy in tactile distance perception on the hand but found no effect of cross-modal adaptation. These results suggests

that looking at another person's hand does not modulate the model of body size in the same way as the visual alteration of one's own body reported by Taylor-Clarke et al. (2004).

In Experiment 2, I investigated whether haptic exploration of a 3D model of a thin or fat body can produce aftereffects in the perception of visual test stimuli. I found an effect in the thin but not fat adaptation condition. These results may suggest that haptic exploration can produce adiposity cues which affect visual perception. The lack of transfer in the fat adaptation condition may suggest that in haptic exploration people rely on additional adiposity cues such as firmness/softness of the body. However, more research is needed to determine whether the effect found in the thin condition was due to body size and shape adaptation.

The cross-category aftereffects reported here (dz = 0.61) are smaller than the aftereffects in body to body adaptation studies (range of dz = 1.34 - 2.07), and comparable to those in cross-category adaptation between bodies and body parts (range of dz = 0.65 – 0.9) showing that although adaptation evokes stronger aftereffects within one modality there is a partial transfer even when the test and the adapting stimuli belong to different sensory modalities.

It can be argued that adaptation in my studies was too short for the full cross-modal transfer to occur. Previous research showed that the strength of the aftereffects depends on adaptation duration (Hershenson, 1993; Leopold, Rhodes, Muller & Jeffery, 2005; Ghuman et al, 2010). There is not much evidence, however, that longer adaptation can produce aftereffects that are qualitatively different. However, Cuturi and MacNeilage (2014) found cross-modal transfer of motion aftereffects only in the longest adaptation condition which lasted 15 seconds. Although the timeframe of this experiment is different than in my studies, this finding suggests that the length of the adaptation can produce qualitatively different aftereffects. Taylor-Clarke et al. (2004) showed that one-hour visual exposure to an altered image of participants' hand and forearm affected tactile perception. However, the authors replicated their results with visual exposure lasting 5 minutes. The timing parameters in the studies discussed here were based on my previous adaptation experiments but also dictated by the practical issues such as the overall duration of the experiment. In Experiment 1, the initial

visual adaptation lasted one minute with an addition of a top up adaptation of 3 seconds on each trial. In Experiment 2, participants haptically explored the adaptor for 2 minutes at the beginning of the task and then for additional 6 seconds on each trial. Similar adaptation duration was sufficient to induce aftereffects within visual modality as described in previous chapters. It remains an open question whether longer adaptation duration would provide stronger evidence for a cross-modal adaptation.

Chapter 7: Distal biases in knuckles localization

7. 1. Introduction

In my main line of research, I investigated the malleability of body image and the extent to which it can be affected by visual exposure to other bodies. I studied both representations of the whole body, as well as body parts. The malleability of the representations of body parts, specifically hands, and the way visual experience affects them is also the topic of my second line of research. In a series of experiments, I investigated the distal bias in the localization of the knuckles, following up on the previous findings by Longo (2015) and Margolis and Longo (2015) which I discussed briefly in Chapter 1. Here, I present this line of research in more detail and describe the results of four experiments conducted as a part of my doctoral research. First, in Experiment 1 and 2, I further investigated whether information from different modalities, i.e. vision and touch, contributes to distal biases and whether these mislocalizations are affected by visual cues such as the crease at the base of the fingers on the palmar hand surface. Next, in Experiment 3 and 4, I investigated whether visual exploration of the participant's own hand in movement, i.e. observing the fingers bending or splaying, can update the representation of the hand and eliminate distal bias.

Hands are ubiquitous in our daily lives. It is through the hands that we experience the world around us most directly. They are especially important for goal-directed action and in learning to manipulate objects (Klatzky, Pellegrino, McCloskey, & Doherty, 1989; Reed, Grubb, & Steele, 2006). From infancy, humans use their hands for two primary functions: to acquire information and to manipulate their environments (Jones & Lederman, 2006). Hands are also a valuable source of social knowledge, providing information about other people's intentions (Woodward, 2009) as well as aiding language comprehension (McNeill, 1992; Goldin-Meadow & Wagner, 2005). We use hands to communicate before we learn language. By 11 months, infants can recognize and use pointing gestures (Carpenter, Nagell, & Tomasello, 1998), and show shifts of attention in the direction of dynamic points even earlier

(Rohlfing, Longo, & Bertenthal, 2012; Bertenthal, Boyer, & Harding, 2014). A recent study which analyzed data from head cameras worn by infants found that while faces are a dominant visual input during the first year of life, hands emerge as dominant in the second year (Fausey, Jayaraman, & Smith, 2016).

With all the experience we gather through the lifespan, it seems that we really should know hands like the proverbial "back of our hand". However, as I discussed in Chapter 1, previous research has revealed that hands representations can be strikingly distorted. Longo and Haggard (2011) showed that on the hand the distance between two unseen touches aligned with the medio-lateral axis (across the hand) is perceived as substantially larger than the same distance aligned with the proximo-distal axis (along the hand). Similarly, using a proprioceptive localization task, Longo and Haggard (2010) found distortions suggesting that in body representations underlying position sense the hand is represented as wider than it actually is and the fingers as shorter than they actually are. However, Longo, Mattioni and Ganea (2015) showed that hand distortions in the proprioceptive localization task were correlated with the magnitude of the mislocalization of the knuckles. Furthermore, a recent study by Saulton, Bülthoff and de la Rosa (2017) demonstrated that after correcting for the conceptual bias of the knuckles location, distortions in hand representations were similar to those present in representations of objects. These results suggested that hand distortions measured in localization tasks (Longo and Haggard, 2010) may be partially driven by a general misconception about hand landmark locations, i.e. the conceptual bias in the location of the knuckles.

Distal mislocalizations of the knuckles (i.e., the metacarpophalangeal joints) have been previously reported by Longo (2015) and Margolis and Longo (2015) who showed that people have highly distorted conceptual knowledge of the configuration of landmarks within their hand, judging their knuckles to be substantially farther forward in the hand than they actually are. Longo (2015) asked participants to lay their hand palm-up on a table (in a position in which knuckles are not visible) and to use a long baton to indicate the location on the palm directly opposite the knuckle of each finger using the other hand. Participants performed the

task either using both vision and touch (Experiment 1), or using the touch alone while blindfolded (Experiment 2). In Experiment 3, participants judge the knuckles location on the palm of the experimenter's hand. In all experiments, participants consistently judged their knuckles as farther forward in the hand than they actually are, showing a clear distal bias for all fingers aside from the thumb. These results suggests that the distortion reflects conceptual knowledge about the configuration of hands in general, rather than self-specific representation of one's own hand. In the study of Margolis and Longo (2015), similar distal biases were apparent when participants were asked to judge the location of their knuckles by clicking the mouse cursor on an empty silhouette, created from an image of the dorsal side of their hand, presented on a screen in front of them.

These findings show that healthy participants can demonstrate behavior similar to this observed in clinical disorders characterized by distorted body representations such as autotopagnosia in which patients are impaired in judgments about the configuration and location of body parts (Buxbaum & Coslett, 2001; Sirigu, Grafman, Bressler, & Sunderland, 1991). Autotopagnosic patients are generally impaired when asked to point to parts of their own body, and are also impaired when asked to point to parts of other people's bodies or mannequins (Gerstmann, 1942; Ogden, 1985; Sirigu et al., 1991). This condition is thought to reflect damage to the body structural description, which mediates knowledge of the spatial layout of bodies (Schwoebel & Coslett, 2005; Corradi-Dell'Acqua et al., 2008; Longo et al., 2010). The distal biases (Longo, 2015; Margolis & Longo, 2015), thus, suggest that even in healthy people the body structural description does not provide a fully veridical representation of body configuration, but is systematically distorted in stereotyped ways across people.

Another example of systematic distortions becomes apparent when healthy people are asked to draw a face. A study by Carbon & Wirth (2014) showed that in all drawings the eyes are positioned much higher in the head than they really are. The authors explained this bias by suggesting that people do not take into account the convexity of the forehead. Similarly, Longo (2015) suggested that distal bias in knuckles localization reflects "intuitive anatomy", a naïve belief about the structure of the hand.

Could these distortions instead reflect a more basic perceptual bias resulting from specific sensory cues present while participants perform the task? One potential interpretation of this effect is that participants, in giving their judgments, were visually influenced by the crease at the base of the fingers on the palmar hand surface, which is substantially farther forward in the hand than the knuckle. However, while responses in Longo (2015) were clearly distal to the actual location of the knuckle, they were also clearly proximal to the crease, suggesting that participants had not simply confused the crease for the knuckle. Furthermore, in Experiment 2 of the study of Longo (2015) similar distal biases were found when participants were blindfolded, suggesting that the bias is not a purely visual bias in the direction of the crease.

Hands are common in our visual experience of the world, but are ubiquitous in touch, in which the fingertips form a 'fovea' for tactile perception (Mancini et al., 2013). In the study by Longo (2015) participants showed distal biases in knuckles localization on the palm even when blindfolded, providing some indication that immediate vision may not be required to elicit this effect. However, it has not been directly assessed how similar in magnitude the biases is between conditions within a single group of participants and the comparison of visual-tactile and tactile-only judgments was between experiments. Therefore, it remains unclear what kind of sensory information affects these distal biases, and how and to what extent visual and tactile cues might affect them. If indeed distal biases arise from a common, modality-independent cause, it would suggests that distal bias is a conceptual distortion. Which in turn raises the question, whether updating the conceptual knowledge can affect the bias.

In this chapter, I describe a series of experiments exploring distal biases. In Experiment 1, I used the paradigm of Longo (2015) to investigate the contribution of vision and touch to knuckle mislocalization. Participants judged the location of their knuckles (the metacarpophalangeal joints) by pointing on their palm in three conditions: (1) using a baton on the skin providing both visual and tactile cues (*VisuoTactile* condition), (2) using a laser pointer resulting in only visual cues (*Visual* condition), or (3) using that baton while blindfolded resulting in just tactile cues (*Tactile* condition). In Experiment 2, I used the

paradigm of Margolis and Longo (2015) to directly assess the potential role of the creases at the base of the fingers as a visual cue in producing the bias. Participants localized their knuckles by clicking the mouse cursor on either a photograph of their palm or on a blank white silhouette of the palm, in which visual cues such as the crease were removed. In Experiment 3, I investigated investigated whether distal bias can be eliminated by careful inspection of participant's own hand in movement. Participants performed a knuckles localization task (the same as in Experiment 1, in *VisuoTactile* condition) before and after an intervention. During the intervention, participants observed their hand while bending their fingers against the thumb in a way which attracted attention to the knuckles and made their location apparent. In Experiment 4, I investigated whether the reduction in distal bias was related to the type of movement performed during the intervention. Participants performed the knuckle localization task three times: before any intervention, after inspecting the hand while splaying the fingers and after inspecting the hand while bending the fingers.

7. 2. Experiment 1

Experiment 1 tested whether both visual and tactile information contribute to the distorted representation of hand structure (Longo, 2015). Participants were asked to localize their knuckles by indicating the location on their palm directly opposite to each knuckle. In the *VisuoTactile* condition, participants used a long baton to make their judgments and could see where they were pointing, providing both visual and tactile information about their response. In the *Tactile* condition, participants used the same baton, but were blindfolded, and thus forced to rely on tactile information to make their judgments. In the *Visual* condition, participants used a laser pointer to indicate their response, resulting in similar visual cues to the VisuoTactile condition, though tactile information was not present on the palm. If the distal biases in knuckle localization are driven by visual signals, then they should emerge in the VisuoTactile and Visual conditions, but not in the Tactile condition. If the biases are driven by tactile signals, then they should appear in the VisuoTactile and Tactile conditions, but not

in the Visual condition. By contrast, if the biases reflect genuine misconceptions about hand structure, they should appear in all three conditions, irrespective of which sensory cues are available.

7. 2. 1 Methods

Participants

Twenty participants (mean age ± SD = 29.9 ± 13.6, range: 19-75, 13 females) took part in this experiment. Nineteen were right-handed and one person was left-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971; mean: 82; range: -61–100). All participants gave informed consent and were paid for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Procedures

The experimental procedures were similar to that of Longo (2015). Participants sat with their left hand resting palm up on a table. Based on the results from Longo (2015) who found no significant difference in knuckle mislocalization between left and right hands, I decided to test only the left hand to reduce the length of the experiment. A webcam (Logitech Webcam Pro 9000 HD) was suspended from a tripod directly above the table. On each trial, I took a photograph (1600 x 1200 pixels) of the participant's response using a custom MATLAB (Mathworks, Natick, MA) script. A 10 cm ruler on the table allowed conversion between distances defined in pixels and in cm.

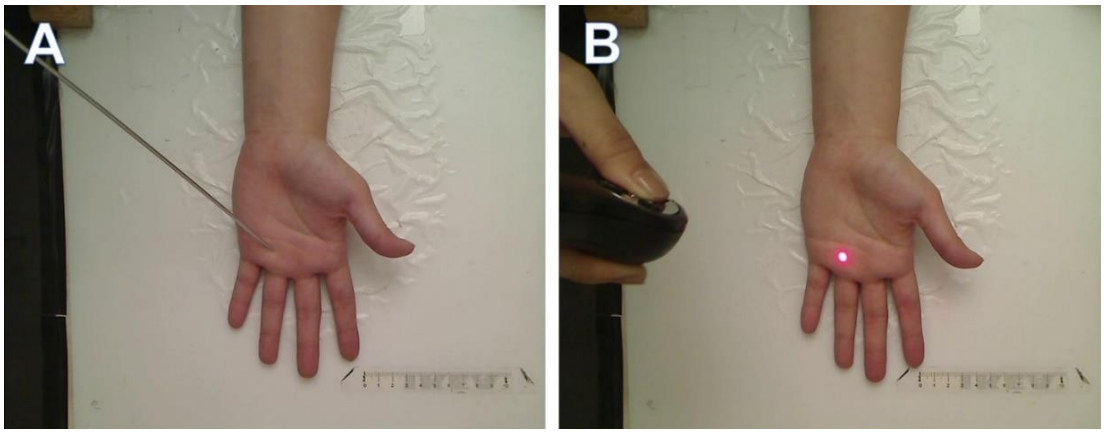

Figure 7.1: Conditions in Experiment 1. *Panel A*: In the *VisuoTactile* and *Tactile* conditions, participants used a long metal baton to indicate the location on their palm directly opposite each of their knuckles. In the VisuoTactile condition participants could also see their response, whereas in the Tactile condition they were blindfolded. Responses were captured by an overhead camera. *Panel B*: In the Visual condition, participants used a laser pointer to indicate their responses.

I explained to the participant that their task was to indicate the location on the palm directly opposite to the knuckle "as if you were to drill directly through the hand". Then I pointed at the knuckles all the way at the base of the fingers of my own hand (on the dorsal side) to make sure participants understood which landmark they were asked to localize (i.e., the metacarpophalangeal joint). Across trials, participants were asked to localize the knuckles of each of the five fingers of their left hand.

On each trial, I gave the participant a verbal instruction about which of their knuckles to localize, by naming one of the five fingers. In each condition, participants judged the location of their knuckles by pointing to the location on their palm directly opposite each knuckle. In the VisuoTactile condition, the participant indicated their response using a metal baton for precision (35-cm length and 2-mm diameter) (see Figure 7.1A). In the Tactile condition, the participant used the same metal baton while blindfolded. In the Visual condition, the participant used a laser pointer (see Figure 7.1B). The diameter of the laser on the solid surface was approximately 2 mm, on the skin the light dispersed to 5-6 mm.

Participants were instructed to be careful and deliberate in their responses, which were unspeeded. They were free to move the baton or the pointer as much as they liked and to adjust

their response until they were satisfied. When the participant indicated verbally that they were happy with their response, I pressed a button on the keyboard to capture the photograph. To avoid hysteresis effects, participants moved the baton to the right side of the table after each response.

There were six experimental blocks (two blocks of each condition) presented in ABCCBA order, with the order of the first three conditions randomized for each participant. Each block consisted of 25 trials, each including five trials of each finger in random order. To allow calculation of the actual location of each knuckle, at the end of the experiment a photograph was taken of the back of the participant's left hand. To avoid ambiguity in coding, I made a small black mark on each knuckle in the center of the bump formed by each knuckle when the participant made a fist.

Analysis

As in the study of Longo (2015), for each photograph the x–y pixel coordinates were coded for the tip of the finger being judged and for the participant's response (the judged location of the knuckle). From these coordinates, I calculated the distance from the participant's judgment to the location of the fingertip in pixels and then converted this number to centimeters. The actual distance from each knuckle to the fingertip was calculated from the photograph of the back of the hand taken at the end of the experiment. Next, the distal bias was calculated as the difference between the distances from the tip to the responses and the actual distance between the fingertip and the knuckle location. Finally, this difference (distal bias) was expressed as a percentage of the actual finger's length. Thus, values greater than 0 indicate that participants judged the knuckle as too far forward in the hand (too close to the fingertip), while values less than 0 indicate that they judged the knuckle as too far back (too close to the wrist).

I decided to focus my analysis on the distal-proximal dimension for two reasons. Firstly, I wanted to keep the analysis as similar as possible to the method used in previous studies investigating distal bias (Longo, 2015; Margolis & Longo, 2015). Secondly, my

analysis revealed very little variability in the dimension perpendicular to the finger midline (calculated as the line going through the middle of the tip and the middle of the crease). For each finger I calculated the angle between the midline (defined as a line going through the middle of the tip and the middle of the crease) and the line going from the tip to the response. This angle was on average 1.52° with very small variability (SD: 0.008°), indicating that responses did not deviate much from the midline (M: 0.20 cm, SD: 0.02).

7. 2. 2 Results and Discussion

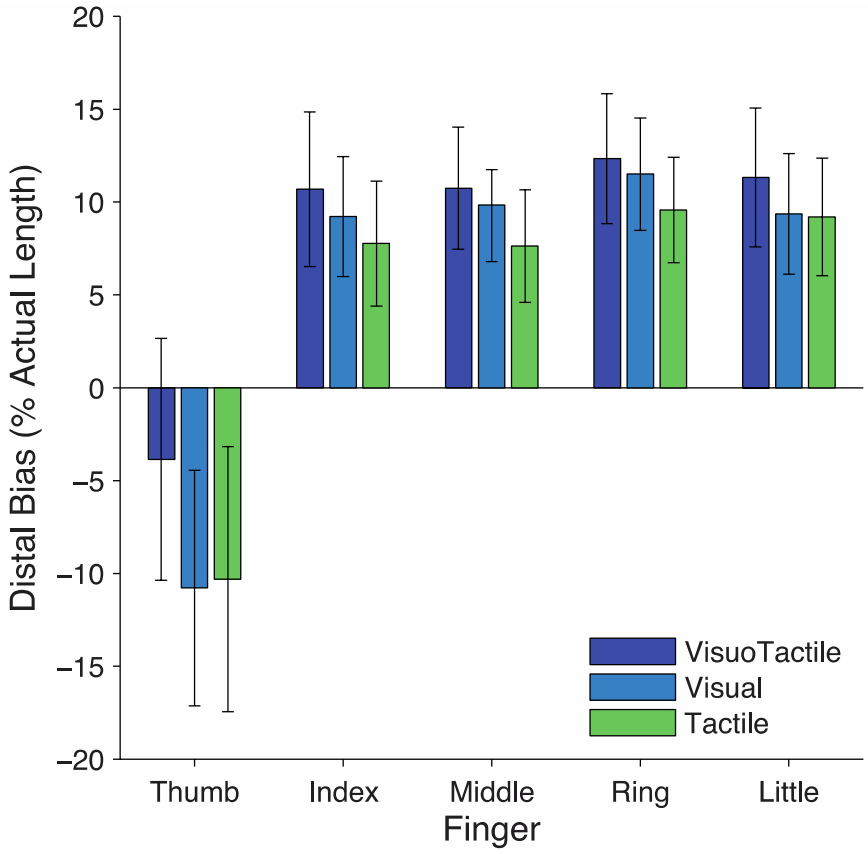

Figure 7.2: Results from Experiment 1. Clear distal biases were apparent for all fingers except the thumb. Error bars represent 95% confidence intervals. Positive values indicate a distal bias (too close to the fingertips), negative values indicate proximal bias (too close to the wrist).

Figure 7.2 shows distal bias for each finger as a percentage of actual finger length. Consistent with the results of Longo (2015), clear distal biases were apparent for all fingers except the thumb. Participants judged their knuckles to be closer to the fingertips than they really are. Critically, these biases were clearly apparent in all three experimental conditions. Table 7.1 summarizes the results, presenting distal biases in centimeters and as a percentage of actual finger length.

Table 7.1 *The results of Experiment 1: distal biases presented in centimeters and as a percentage of finger's length.*

Condition	Finger	Mean distal bias in cm	SE	Mean distal bias as % of finger's length	SE
VisuoTactile	Thumb	-0.21	0.20	-3.86	3.32
	Index	0.95	0.19	10.68	2.13
	Middle	1.06	0.17	10.75	1.68
	Ring	1.14	0.17	12.33	1.78
	Little	0.82	0.14	11.33	1.91
Visual	Thumb	-0.64	0.19	-10.78	3.23
	Index	0.81	0.15	9.22	1.65
	Middle	0.97	0.14	9.85	1.38
	Ring	1.06	0.14	11.50	1.55
	Little	0.67	0.12	9.36	1.66
Tactile	Thumb	-0.61	0.22	-10.31	3.64
	Index	0.68	0.15	7.76	1.72
	Middle	0.75	0.15	7.63	1.54
	Ring	0.88	0.13	9.57	1.45
	Little	0.67	0.12	9.19	1.62

Collapsing across the five fingers, clear distal biases were found in the VisuoTactile condition (*M*: 8.25%), $t(19) = 4.24$, $p < 0.0005$, $d = 1.81$, the Visual condition (*M*: 5.83%), $t(19) = 3.67$, $p < 0.002$, $d = 0.95$, and the Tactile condition (*M*: 4.77%), $t(19) = 2.78$, $p < 0.02$, $d = 0.62$. This bias was even stronger removing the thumb from the analysis, with clear distal biases in the VisuoTactile condition (*M*: 11.27%), $t(19) = 7.80$, $p < 0.00001$, $d = 2.47$, the Visual condition (*M*: 9.98%), $t(19) = 6.96$, $p < 0.00001$, $d = 2.20$, and the Tactile condition

(*M*: 8.54%), $t(19) = 4.31$, $p < 0.0005$, $d = 1.36$. These results clearly replicate the bias in knuckle localization described by Longo (2015), and show that neither visual nor tactile cues are necessary to elicit this effect.

To directly compare the magnitude of biases in the different conditions, I conducted a 3x5 repeated measures analysis of variance (ANOVA) including Condition (VisuoTactile, Tactile, Visual) and Finger (Thumb, Index, Middle, Ring, Little) as within-subjects factors. There was a significant main effect of condition, $F(2, 38) = 6.35$, $p < 0.005$, $\eta_p^2 = 0.25$, and a significant main effect of finger, $F(4, 76) = 40.93$, $p < 0.0001$ $\eta_p^2 = 0.68$. There was also a significant interaction between condition and finger, $F(8, 152) = 5.34$, $p < 0.005$, $\eta_p^2 = 0.22$. A similar ANOVA excluding the thumb revealed a significant main effect of condition, $F(2, 38) = 5.13$, $p = 0.011$, $\eta_p^2 = 0.21$, but no effect of finger, $F(3, 57) = 2.52$, $p = 0.091$, $\eta_p^2 = 0.12$, nor an interaction, $F(6, 114) = 4.27$, $p = 0.147$, $\eta_p^2 = 0.09$.

To investigate the effect of condition I collapsed across the four fingers, excluding the thumb. There was a significant difference between the Tactile and VisuoTactile condition, $t(19) = 3.10$, $p < 0.01$, $d_z = 0.73$, but neither the difference between the VisuoTactile and Visual condition, $t(19) = 1.87$, $p = 0.078$, $d_z = 0.47$, nor between the Tactile and Visual conditions, $t(19) = 1.49$, $p = 0.15$, $d_z = 0.33$ were significant. Thus, the bias appears to be strongest in the VisuoTactile condition.

For the thumb, there was a significant difference between the Visual and VisuoTactile conditions, $t(19) = 4.43$, $p < 0.0005$, $d_z = 0.99$, and between the VisuoTactile and Tactile conditions, $t(19) = 2.76$, $p < 0.02$, $d_z = 0.62$, but not between the Tactile and Visual conditions, $t(19) = 0.22$, $p = 0.824$, $d_z = 0.05$. Looking at each condition individually, there were significant proximal biases for the thumb in both the Visual condition (*M*: -10.78%), $t(19) = -3.33$, $p < 0.005$, $d = 0.75$, and the Tactile condition (*M*: -10.31), $t(19) = -2.83$, $p = 0.01$, $d = 0.63$, but no significant bias in the VisuoTactile condition (*M*: -3.86), $t(19) = -1.16$, $p = 0.26$, $d = 0.26$,. This general pattern is quite similar to that found by Longo (2015), in which a proximal bias was found for the thumb when only tactile cues were available, but no bias

was found when both vision and touch were available, although in that study it was a between experiments comparison

Across the four non-thumb fingers the magnitude of distal biases was strongly correlated between conditions, with large correlations between the Visual and VisuoTactile conditions, $r(18) = 0.93$, $p < 0.00001$, the Tactile and VisuoTactile conditions, $r(18) = 0.87$, $p < 0.00001$, and the Tactile and Visual conditions, $r(18) = 0.79$, $p < 0.00005$.

These results clearly replicate the distal bias in judging the location of the knuckles reported by Longo (2015). Critically, my results show that neither visual nor tactile cues are necessary to produce this effect. Clear distal biases were found for all non-thumb fingers in the absence of visual cues (i.e., in the Tactile condition) and in the absence of tactile cues (i.e., in the Visual condition). Furthermore, the magnitude of biases in individual participants was strongly correlated between the conditions. These results demonstrate that the mislocalization of the knuckles is not an artifact of any specific sensory signal available during responses. This is consistent with the proposal that these biases result from distortions of modality-independent conceptual knowledge of hand structure (Longo, 2015).

Nevertheless, my results do suggest that the type of information available for making judgments does affect the size of the mislocalization bias. For the non-thumb fingers, the bias was strongest in the VisuoTactile condition in which participants used both vision and touch to make their judgments. Thus, the bias became larger the more information was available. This effect seems counterintuitive, as normally people are expected to be more accurate the more information they have. However, the results of the present study showed that in knuckles localization the opposite seems to be the case. Taken together, my findings strongly suggest that distal biases arise from a common modality-independent cause.

7. 3. Experiment 2

The results of Experiment 1 showed that neither vision nor touch is necessary to elicit distal mislocalization of the knuckles. In Experiment 2, I investigated more directly the potential role of visual cues, such as the crease at the base of each finger, in producing these

biases. In order to manipulate visual information, I used the paradigm of Margolis and Longo (2015) in which participants respond by clicking the mouse cursor on an image of their hand. In the study by Margolis and Longo (2015) participants localized their knuckles on an empty silhouette created from an image of the dorsal side of the hand. Here, I used the same paradigm but with a silhouette created from an image of participant's palm. Participants were asked to indicate the location directly opposite their knuckles on either a full-colour photograph of their palm (*Photo* condition) or on a silhouette of the palm where visual cues such as crease were removed (*Silhouette* condition). To the extent that distal biases in knuckle localization are driven by the presence of visual landmarks, biases should be larger in the Photo condition than the Silhouette condition.

7. 3. 1. Methods

Participants

Twenty participants (mean age ± SD = 25 ± 8.07, range: 18-49, 17 females) took part in this experiment. Initial analysis of the data showed that one of the participants confused the ring and index fingers on approximately half of the trials and his data was therefore excluded from further analysis. Of the remaining nineteen participants (mean age ± SD = 25.26 ± 8.2, range: 18-49, 17 females), seventeen were right-handed (above 50) and two were mixed-handed (between -50 and 50) as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971; mean: 75; range: -40–100). Participants gave informed consent and received payment for their participation. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Procedures

At the start of the experiment, I took a photograph of the palm of the participant's left hand against a black background using a webcam (Logitech Webcam Pro 9000 HD) suspended from a tripod directly above the table. A ruler was placed next to participant's hand and included in the photograph to allow conversion from pixels to centimeters later in the analysis.

Then, I cropped the photograph and edited it in the GNU Image Manipulation Program (GIMP, version 2.8.8) to create two images (800 pixels × 800 pixels) that were identical in size, shape and location of the hand (see Figure 7.3). The ruler was not included in the final images. The second image was additionally edited using the Threshold tool in GIMP to obtain a white silhouette of participant hand on a black background with cues such as creases removed from the image (see Figure 7.3B). While I was editing the pictures the participant filled in the handedness questionnaire.

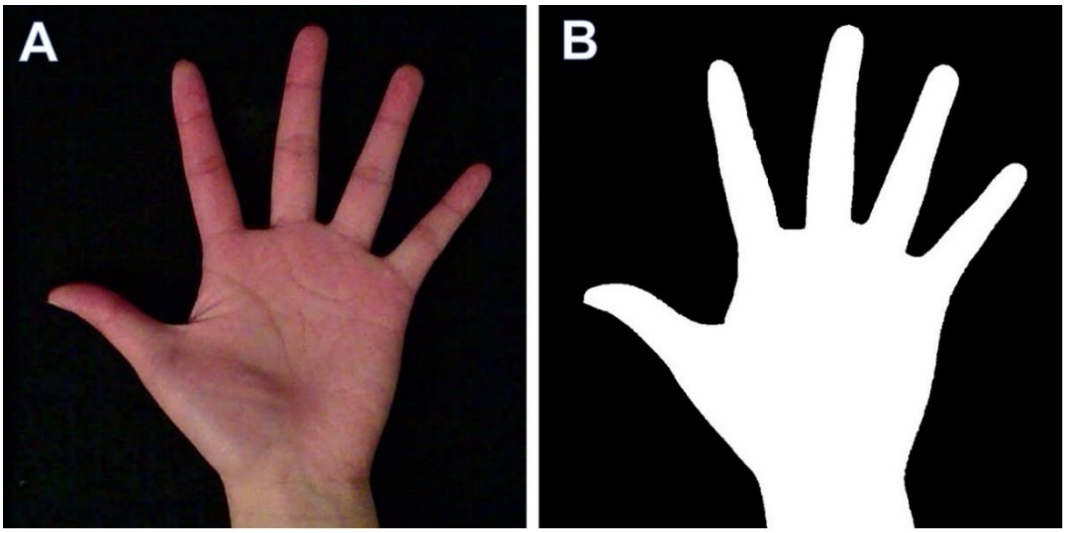

Figure 7.3: Conditions in Experiment 2. *Panel A*: Sample stimulus in the Photo condition. A photograph was taken of the participant's hand at the beginning of the session and incorporated into the experimental script. *Panel B*: Sample stimulus in the Silhouette condition. The silhouette was made directly from the photograph of each participant's hand using the GNU Image Manipulation Program. The two hands thus had exactly the same size, posture, and overall contour. In both conditions participants localized their knuckles by clicking the mouse cursor (a cross) on the corresponding location of the hand image.

Next, I explained that the task involved identifying the location directly opposite to the knuckles on either a photograph or a silhouette of the participant's palm. As in Experiment 1, I explained that I was interested in the knuckle all the way at the base of the finger (i.e., the metacarpophalangeal joint), and pointed at the knuckles all the way at the base of the fingers

of my own hand (on the dorsal side) to make sure the participant understood which landmark they were being asked to localize.

During the task, on each block either the cropped photograph of the palm of the participant's hand (Photo condition) or the silhouette (Silhouette condition) was shown under control of a custom MATLAB script using Cogent Graphics (developed by John Romaya, Laboratory of Neuroscience, Wellcome Department of Imaging Neuroscience, University College London) and the participant was asked to localize their knuckles. The size of the image presented on the screen roughly matched the actual size of the participant's hand. On each trial, a written instruction was shown at the bottom of the screen, indicating one of the fingers so that the participant knew which knuckle to localize. The participant indicated their response by clicking the mouse cursor (a thin cross) at the corresponding location on the hand image. After each response, the mouse cursor appeared again at a random location on the monitor to reduce hysteresis and make responses as independent from each other as possible.

There were four blocks (two blocks of the photograph and two blocks of the silhouette) presented in ABBA order, with the first condition counterbalanced across participants. Each block consisted of 25 trials, each including five trials of each finger in random order. At the end of the experiment, a photograph was taken of the back of the participant's left hand to allow calculation of actual knuckle location. As in Experiment 1, to avoid ambiguity in coding of knuckle location, I made a small black mark on each knuckle.

Analysis

On each trial, the x–y pixel coordinates of the response (i.e., the judged location of the knuckle) were recorded. During the analysis, I coded the pixel coordinates of the tip of each finger on the monitor as they were shown to each participant. Then, from these coordinates, I calculated the distance from the tip to the response for each trial and converted to centimeters using the ruler from the original photograph. As in Experiment 1, I calculated the actual distance from each knuckle to the fingertip from the photograph of the back of hand taken at the end of the experiment and converted to centimeters. Next, the distal bias was calculated as

the difference between these two distances as a percentage of actual distance, as in Experiment 1.

Again, for each finger I calculated the angle between the midline and the line going from the tip to the response (M: 1.52°, SD: 0.007°), to show that responses did not deviate much from the midline (M: 0.19 cm; SD: 0.02).

7. 3. 2 Results

In both Photo and Silhouette condition, clear distal mislocalizations of the knuckles were found for all fingers except the thumb (Table 7.2).

Table 7.2 *The results of Experiment 2: distal biases presented in centimeters and as a percentage of finger's length.*

Condition	Finger	Mean distal bias in cm	SE	Mean distal bias as % of finger's length	SE
Silhouette	Thumb	-0.01	0.14	-0.31	2.37
	Index	1.15	0.14	12.90	1.52
	Middle	1.56	0.17	15.54	1.58
	Ring	1.45	0.17	15.70	1.72
	Little	1.31	0.14	17.88	1.86
Photo	Thumb	0.02	0.14	0.37	2.42
	Index	1.23	0.12	13.86	1.24
	Middle	1.66	0.15	16.60	1.31
	Ring	1.51	0.16	16.32	1.61
	Little	1.32	0.13	18.03	1.67

Figure 7.4 shows this distal bias as a percentage of actual finger length. This effect was significant for all four non-thumb fingers (all p values < 0.0001). Across all fingers, the distal bias was significant for both the Silhouette condition (M: 12.34 %), $t(18) = 8.83$, $p < 0.00001$, $d = 2.03$, and the Photo condition (M: 13.04%), $t(18) = 10.64$, $p < 0.00001$, $d = 2.44$. As in Experiment 1, the effect was stronger after removing the thumb from the analysis, with clear distal biases in both the Silhouette condition (M: 15.51%), $t(18) = 10.11$, $p < 0.00001$, $d = 2.32$, and the Photo condition (M: 16.20%), $t(18) = 12.28$, $p < 0.00001$, $d = 2.82$.

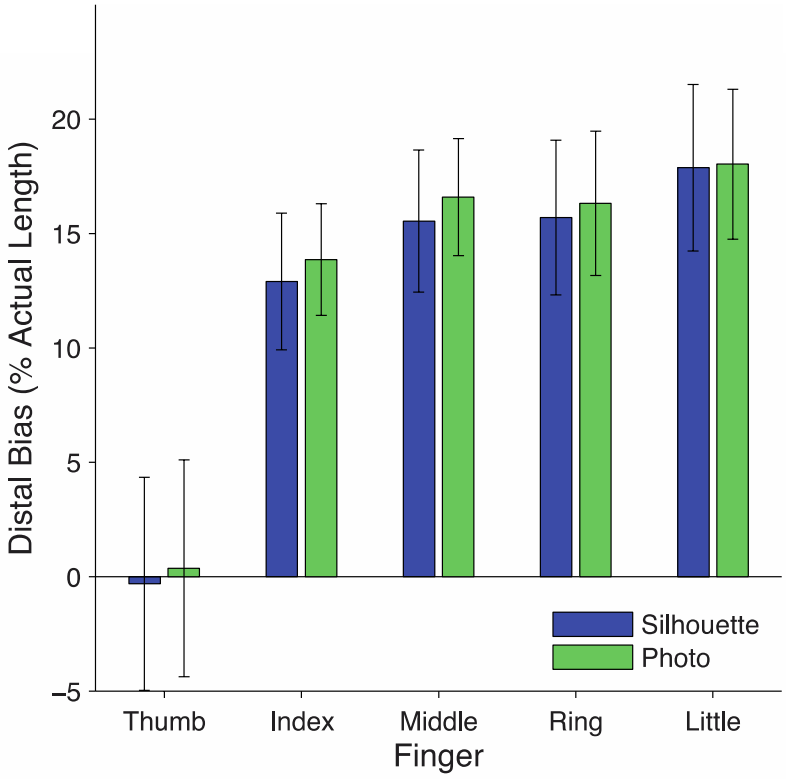

Figure 7.4: Results from Experiment 2. Clear distal biases were apparent for judgments of the location of knuckles of all the fingers except the thumb. These biases were clearly apparent in both the Photo and Silhouette conditions. No significant differences between the two conditions were found. Error bars represent 95% confidence intervals. Positive values indicate distal bias (too close to the fingertip), negative values indicate proximal bias (too close to the wrist).

I conducted a repeated measures ANOVA including Condition (Silhouette, Photo) and Finger (Thumb, Index, Middle, Ring, Little) as within-subjects factors. There was a significant main effect of finger, $F(4, 72) = 31.00$, $p < 0.001$ $\eta_p^2 = 0.63$, reflecting the gross difference between the thumb and the other fingers. There was, however, no significant interaction between condition and finger, $F(4, 72) = 0.50$, $p = 0.736$, $\eta_p^2 = 0.03$. There was also no significant main effect of condition, $F(1, 18) = 3.10$, $p = 0.095$, $\eta_p^2 = 0.15$.

A subsequent ANOVA in which I removed the thumb from the analysis, showed, unlike Experiment 1, a significant main effect of finger, $F(3, 54) = 6.25$, $p = 0.001$, $\eta_p^2 = 0.26$, with the magnitude of distal bias increasing from the index finger to the little finger. Again,

there was no main effect of condition, $F(1, 18) = 2.89$, $p = 0.107$, $\eta_p^2 = 0.14$, nor a significant interaction, $F(3, 54) = 1.89$, $p = 0.142$, $\eta_p^2 = 0.10$. There was a strong correlation between the amount of distal bias on the non-thumb fingers between the two conditions, $r(17) = 0.97$, $p < 0.00001$.

These results suggest that participants did not use creases as landmarks in their judgments of knuckle location. Together with Experiment 1, these results replicate recent findings of systematic mislocalization of the knuckles (Longo, 2015; Margolis & Longo, 2015) and extend them by providing clear evidence showing the robustness of the effect to differences in sensory cues available for response and the nature of the task. The study by Margolis and Longo (2015) showed distal biases in knuckles localization when participants were localizing their knuckles on an empty silhouette created from an image of the back of the hand. Here, I showed that similar biases occur when participants are presented with a silhouette of the palm, suggesting that these biases are not specific to one side of the hand but rather reflect a more general misconception about the location of the knuckles.

These findings indicate that the distal bias is resistant to changes in the stimulus information available for response, suggesting that the bias does not rely on any specific stimulus cue or single sensory modality suggests. This, in turn, indicates that such mislocalisations reflect a conceptual misrepresentation of hand structure. Thus, my next question was whether the conceptual misrepresentation may be updated by careful visual inspection to one's own hand. Specifically, I was interested whether looking at one's own hand in movement, which involved knuckles bending, would eliminate the bias. I addressed this question is Experiment 3.

7. 4. Experiment 3

The results from Experiment 1 and 2 were consistent with previous findings (Longo, 2015; Margolis & Longo, 2015) and suggested that distal bias results from a conceptual misrepresentation. Here, I wanted to investigate whether visual exploration of one's own hand in movement will affect distal bias. Participants first performed the knuckle localization task

as in Experiment 1 (*VisuoTactile* condition). Afterwards, an intervention took place during which participants were asked to observe their hand while bending all four non-thumb fingers against the thumb. Participants were not specifically instructed to figure out the location of the knuckles during the intervention. However, I hypothesized that the context of the previously performed task (knuckles localization) will implicitly cue subjects as to the purpose of the intervention.

7. 4. 1 Methods

Participants

Twenty participants (mean age ± SD = 27.9 ± 12.0, range: 19-64, 10 females) took part in this experiment. All were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971; mean: 87; range: 63 – 100). All participants gave informed consent. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

Procedures

Procedures were very similar to Experiment 1. Participants performed the same task as in *VisuoTactile* condition using a metal baton to indicate the position of the knuckles on the palm (See Figure 7.1 A). I applied the same setup using a webcam to take a picture of the response on each trial. Participants performed the task twice: before and after the intervention. In each condition (*Before* / *After*), the task was divided in two blocks of 25 trials, each including five trials of each finger in random order, resulting in a total of 100 trials per participant. During the intervention, participants were instructed to observe their hand while bending all four non-thumb fingers against the thumb. They inspected their hand from 3 different views: side, front and top (see Figure 7.5), bending their fingers 10 times in each position. Participants were told to pay close attention to the hand and to the movement as there would be questions about it after the experiment. At the end of the experiment, I took a photograph of the back of the participant's left hand to allow calculation of actual knuckle

location. As in Experiment 1 and 2, to avoid ambiguity in coding of knuckle location, I made a small black mark on each knuckle. Afterwards, participants answered a questionnaire (see Table 7.4) consisted of ten statements which they rated on a scale from 1 (completely disagree) to 10 (completely agree).

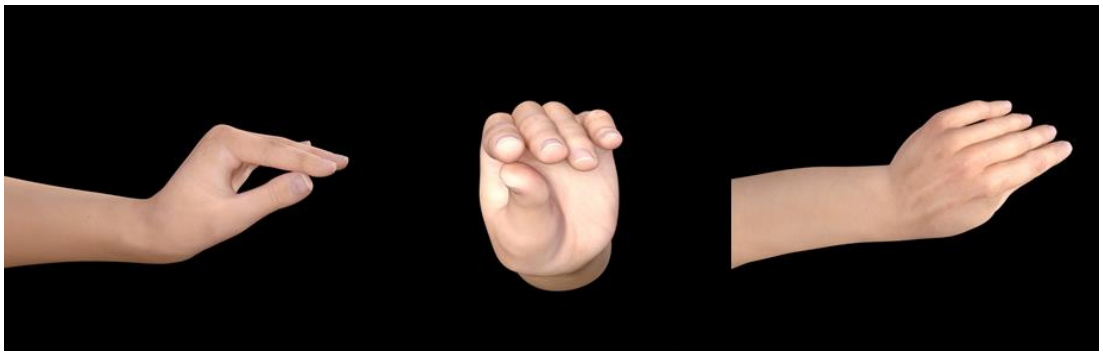

Figure 7.5: Intervention in Experiment 3. During intervention participants observed their own hand from three different perspectives while bending all four non-thumb fingers against the thumb.

Analysis

Analysis were the same as in Experiment 1.

7. 4. 2 Results

Figure 7.6 shows distal bias for each finger as a percentage of actual finger length before and after the Intervention. Consistent with the previous results of Longo (2015) and with the results of Experiment 1 and 2, clear distal biases were apparent for all fingers except the thumb. Participants judged their knuckles to be closer to the fingertips than they really are. Critically, these biases were clearly apparent both before and after the Intervention. Table 7.3 summarizes the results, presenting distal biases in centimeters and as a percentage of actual finger length.

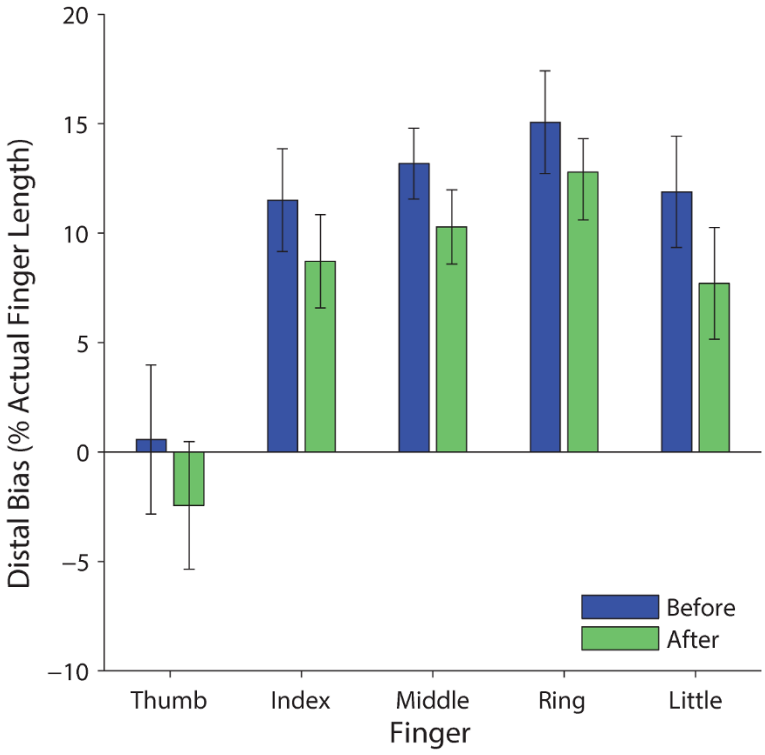

Figure 7.6 Results of Experiment 3. Clear distal biases were apparent for all fingers except the thumb. Error bars represent 95% confidence intervals. Positive values indicate a distal bias (too close to the fingertips), negative values indicate proximal bias (too close to the wrist).

Collapsing across the five fingers, clear distal biases were found both Before (M: 9.48 %, SD = 3.24): $t(19) = 13.11$, $p < 0.0001$, $d = 2.93$, and After the intervention (M: 7.38 %, SD = 3.80): $t(19) = 8.68$, $p < 0.0001$, $d = 1.94$. The distal biases were even stronger after removing the thumb from the analysis. Clear distal biases were found both Before (M: 12.00 %, SD = 1.56): $t(19) = 7.69$, $p < 0.0001$, $d = 3.31$, and After the intervention (M: 10.00 %, SD = 0.84): $t(19) = 11.87$, $p < 0.00001$, $d = 2.42$.

These results showed that the intervention did not eliminate the bias. However, further analysis showed that the distal bias after the intervention was significantly reduced: a 2x5 repeated Measures ANOVA with factors time (*Before* / *After*) and finger revealed a main effect of time: $F(1,19) = 9.13$, $p = 0.007$, $\eta_p^2 = 0.33$. There was also a main effect of finger: $F(4,76) = 22.58.$, $p < 0.001$, $\eta_p^2 = 0.54$ but no interaction: $F(4,76) = 0.80$, $p = 0.531$, $\eta_p^2 = 0.04$.

Table 7.3. *The results of Experiment 3: distal biases presented in centimeters and as a percentage of finger's length.*

Condition	Finger	Mean distal bias in cm	SE	Mean distal bias as % of finger's length	SE
Before Intervention	Thumb	0.13	0,12	1,23	1,95
	Index	0,90	0,11	10,13	0,96
	Middle	1,23	0,11	12,19	0,65
	Ring	1,29	0,13	13,44	0,97
	Little	0,80	0,10	10,44	1,05
After Intervention	Thumb	0,01	0,11	0,28	1,86
	Index	0,73	0,09	8,01	0,89
	Middle	1,04	0,10	9,85	0,92
	Ring	1,15	0,12	11,42	1,18
	Little	0,60	0,09	7,37	1,16

These results showed that after the intervention participants judged their knuckles to be closer to the actual location of the knuckles, i.e. away from the fingertips and closer to the wrist. The results of the questionnaire showed that there was a clear positive correlation between the reduction of distal bias and Q4: *After seeing my fingers bending, I felt like I judged my knuckles as closer to my wrist*: $r(18)$[5] = 0.66, p = 0.002. Furthermore, there was a negative correlation between the reduction of distal bias and Q3: *After seeing my fingers bending, I felt like I judged my knuckles as closer to my fingertips*: $r(18)$ = - 0.66, p = 0.002. These results show that participants had insight into the direction of the change, i.e. bias reduction, which suggests that participants updated their conceptual representation of the hand. There was no significant correlation between the reduction of distal bias and other questions from the questionnaire.

Thus, the results of Experiment 3 suggests that looking at the fingers bending reduced but did not eliminate distal biases. It was not clear, however, whether the reduction in the magnitude of the bias was caused simply by the observation of the hand or whether it was due

[5] The correlations are based on n = 19, since one of the participants did not complete the questionnaire.

to the specific movement involving bending the fingers in a way which attracted attention to the knuckles and made their location apparent. Therefore, in the next step, I wanted to investigate whether the reduction in distal bias was related to the type of movement performed during the intervention.

Table 7.4. *The results of the questionnaire used in Experiment 3. The columns show the mean responses (on the scale from 1 to 10), standard deviation and the correlation between the mean responses and the reduction of the bias measured as a difference between the results Before and After the intervention.*

Question	Mean response	SD	R (correlation with the bias reduction)
Q1: Looking at my fingers bending, I was surprised by where my knuckles were.	4.26	2.21	-0.35
Q2: I felt like I localised my knuckles differently after seeing my fingers bending than before.	4.95	3.10	-0.22
Q3: After seeing my fingers bending, I felt like I judged my knuckles as closer to my fingertips.	2.37	1.26	0.66*
Q4: After seeing my fingers bending, I felt like I judged my knuckles as closer to my wrist.	5.37	3.18	-0.66*
Q5: I felt like I had better understanding of the mechanics of my knuckles after seeing my fingers bending than before.	6.11	2.42	-0.09
Q6: I felt like I had a worse understanding of the mechanics of my knuckles after seeing my fingers bending than before.	1.47	1.02	0.15
Q7: Before looking at my fingers bending, I felt like my knuckles were more a part of my hand than a part of my fingers.	5.68	2.65	-0,09
Q8: Before looking at my fingers bending, I felt like my knuckles were more a part of my fingers than a part of my hand.	3.42	2.39	0.10
Q9: After looking at my fingers bending, I felt like my knuckles were more a part of my hand than a part of my fingers.	4,84	2,79	-0,23
Q10: After looking at my fingers bending, I felt like my knuckles were more a part of my fingers than a part of my hand.	4,42	2,85	0,28

7. 5. Experiment 4

Results from Experiment 3 showed that distal bias in knuckles localization was reduced but not eliminated by careful inspection of one's hand in movement. Here, I wanted to investigate whether this reduction in distal bias was related to the type of movement performed during the intervention. I designed a control experiment with a different

intervention in which participants observed their hand while splaying and un-splaying the fingers. The knuckle joints were not involved in any obvious way in this movement. To build in a replication of the result from Experiment 3, participants underwent both interventions in a fixed order: fingers splaying (Intervention 1) and fingers bending (Intervention 2). The order of the interventions was fixed, rather than counterbalanced, as I expected the effect of fingers bending, and the subsequent update in the conceptual representation of the hand, would carry over to the next block. Thus, participants performed the knuckles localization task three times: before any intervention, after Intervention 1, and after Intervention 2.

7. 5. 1 Methods

Participants

Twenty participants (mean age ± SD = X ± X, range: 20-42, 11 females) took part in this experiment. Nineteen were right-handed and one person was left-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971; mean: 82; range: -61 – 100). All participants gave informed consent. The procedures were approved by the ethics board of the Department of Psychological Sciences, Birkbeck, University of London.

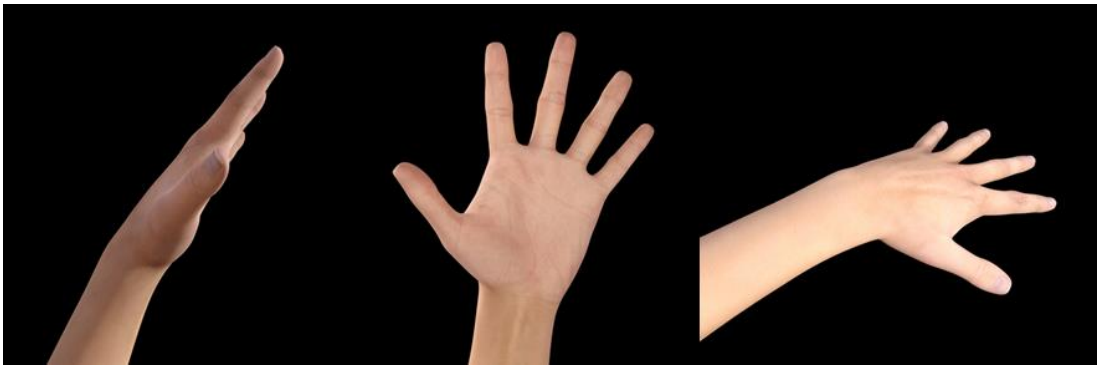

Figure 7.7: Intervention 1 in Experiment 4. During intervention participants observed their own hand from three different perspectives while splaying and un-splaying the fingers.

Procedures

Procedures were similar as in Experiment 1 and 3. Participants performed the task three times: before any intervention, after *Intervention 1* and after *Intervention 2*. In each condition, the task was divided in two blocks of 25 trials, each including five trials of each finger in random order, resulting in 150 trials in total. During Intervention 1, participants were instructed to observe their hand while spreading the fingers. Again, they were inspecting their hand from 3 different views: side, front and top (See Figure 7.7), spreading their fingers 10 times in each position. Participants were told to pay close attention to the hand and the movement as there will need to answer questions about it after the experiment. Intervention 2 was the same as in Experiment 3. As in Experiment 1-3, at the end of the experiment, I took a photograph of the back of the participant's left hand with a small black mark on each knuckle to allow calculation of actual knuckle location. Afterwards, participants answered a questionnaire (see Table 7.6) consisted of twelve statements which they rated on a scale from 1(completely disagree) to 10 (completely agree).

Analysis

Analysis were the same as in Experiment 1 and 3.

7. 5. 2 Results

Results are shown in Figure 7.7. Participants judged their knuckles to be closer to the fingertips than they really are: clear distal biases were apparent for all fingers except the thumb. Critically, these biases were apparent in all three conditions: before any intervention, after *Intervention 1* and after *Intervention 2*. Table 7.5 summarizes the results, presenting distal biases in centimeters and as a percentage of actual finger length.

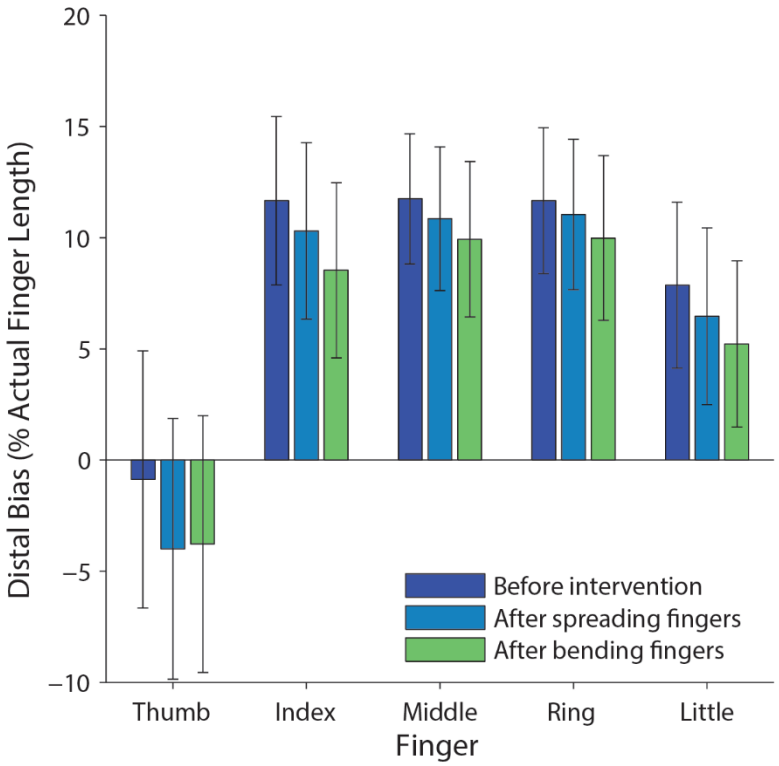

Figure 7.8: Results of Experiment 4. Clear distal biases were apparent for all fingers except the thumb. Error bars represent 95% confidence intervals. Positive values indicate a distal bias (too close to the fingertips), negative values indicate proximal bias (too close to the wrist)

Collapsing across the fingers, clear distal bias was found in all conditions. Before any intervention participants judged their knuckles to significantly closer to the fingertips (M: 8.41 %, SE = 1.80): $t(19) = 4.67$, $p < 0.001$, $d = 0.96$. The distal bias was also apparent after *Intervention 1* (splay) (M: 6.93%, SE = 1.89): $t(19) = 3.67$, $p = 0.0016$, $d = 0.73$ and after *Intervention 2* (bending) (M: 5.98 %, SE = 1.89): $t(19) = 3.16$, $p = 0.005$, $d = 0.78$. The bias was even more apparent after removing the thumb from the analysis. Before any intervention the distal bias was M = 10.73% (SE = 2.48): $t(19) = 4.34$, $p < 0.001$, $d = 1.37$; after *Intervention 1*, M = 9.67% (SE = 2.92): $t(19) = 3.31$, $p = 0.0018$, $d = 1.04$; and after *Intervention 2*, M = 8.42% (SE = 2.8): $t(19) = 3.01$, $p = 0.0036$, $d = 0.95$.

Table 7.5. *The results of Experiment 4: distal biases presented in centimeters and as a percentage of finger's length.*

Condition	Finger	Mean distal bias in cm	SE (cm)	Mean distal bias as % of finger's length	SE (%)
Before Intervention	Thumb	-0.4	0.19	-0.87	2.95
	Index	1.09	0.19	11.66	1.93
	Middle	1.22	0.16	11.75	1.49
	Ring	1.12	0.17	11.67	1.67
	Little	0.59	0.14	7.86	1.91
Intervention 1	Thumb	-0.23	0.19	-3.99	2.99
	Index	0.96	0.19	10.30	2.02
	Middle	1.12	0.17	10.86	1.65
	Ring	1.06	0.17	11.04	1.73
	Little	0.48	0.15	6.47	2.03
Intervention 2	Thumb	-0.23	0.19	-3.78	2.95
	Index	0.79	0.19	8.53	2.01
	Middle	1.03	0.19	9.93	1.78
	Ring	0.97	0.19	9.98	1.89
	Little	0.39	0.14	5.22	1.91

However, further analysis showed that both interventions significantly reduced distal biases. A 3 x 5 repeated measures ANOVA with factors time and finger showed the main effect of time: $F(2,38) = 4.16$, $p = 0.023$, $\eta_p^2 = 0.18$, and finger: $F(4,76) = 31.19$, $p < 0.001$, $\eta_p^2 = 0.62$, but no interaction: $F(8,152) = 1.48$, $p = 0.17$, $\eta_p^2 = 0.07$. Post hoc tests (Holm corrected) showed a significant difference between the magnitude of the bias measured before any intervention and after *Intervention 1*: M = 1.48%, SE = 0.45, $t(19) = 3.32$, $p = 0.003$ as well as measured after *Intervention* 1 and after *Intervention 2*: M = 0.96%, SE = 0.37, $t(19) = 2.61$, $p = 0.011$. The biggest difference was observed between the magnitude of the bias measured before any intervention and after *Intervention 2*: M = 2.44%, SE = 0.55, $t(19) = 4.47$, $p < 0.001$. These results show a clear, gradual reduction of the distal bias between the conditions.

Table 7.6. *The results of the questionnaire used in Experiment 4. The columns show the mean responses (on the scale from 1 to 10), standard deviation and correlations between the question and the reduction of the bias between the conditions.*

Question	Mean	SD	R (Before – Intervention 1)	R(Intervention 1 – Intervention 2)	R (Before – Intervention 2)
Q1: Looking at my fingers spreading (task 1), I was surprised by where my knuckles were.	3.30	1.87	0.55*	-0.39	0.22
Q2: Looking at my fingers bending (task 2), I was surprised by where my knuckles were.	4.80	2.88	0.36	0.32	0.32
Q3: I felt like I localised my knuckles differently after seeing my fingers spreading (task 1) than before.	3.90	2.38	-0.27	-0.27	0.21
Q4: I felt like I localised my knuckles differently after seeing my fingers bending (task 2) than before.	5.50	3.00	0.20	0.20	0.20
Q5: After seeing my fingers spreading (task 1), I felt like I judged my knuckles as closer to my fingertips.	3.15	2.52	-0.09	0.00	-0.07
Q6: After seeing my fingers spreading (task 1), I felt like I judged my knuckles as closer to my wrist.	4.10	3.06	0.49*	-0.25	0.26
Q7: After seeing my fingers bending (task 2), I felt like I judged my knuckles as closer to my fingertips.	3.45	2.46	0.13	-0.20	-0.01
Q8: After seeing my fingers bending (task 2), I felt like I judged my knuckles as closer to my wrist.	5.35	3.18	0.41	0.27	0.50*
Q9: I felt like I had better understanding of the mechanics of my knuckles after seeing my fingers spreading (task 1) than before.	4.70	2.62	0.43	-0.55*	0.03
Q10: I felt like I had worse understanding of the mechanics of my knuckles after seeing my fingers spreading (task 1) than before.	2.10	1.77	0.18	0.14	0.23
Q11: I felt like I had better understanding of the mechanics of my knuckles after seeing my fingers bending (task 2) than before.	5.95	2.76	0.23	0.00	0.19
Q12: I felt like I had a worse understanding of the mechanics of my knuckles after seeing my fingers bending (task 2) than before.	2.05	1.64	-0.04	0.28	0.13

The results of the questionnaire, presented in Table 7.6, showed a significant positive correlation between Q6: *After seeing my fingers spreading (task 1), I felt like I judged my knuckles as closer to my wrist* and the reduction of the bias after *Intervention 1*: $r(19) = 0.49$, $p = 0.03$, suggesting that, as in Experiment 3, participants had some insight into a direction of change in their responses. There was also a significant correlation between Q8: *After seeing my fingers bending (task 2), I felt like I judged my knuckles as closer to my wrist* and the overall reduction of the bias measured as the difference between the baseline before any intervention and the results after *Intervention 2*: $r(19) = 0.49$, $p = 0.0298$. However, the correlation between Q8: *After seeing my fingers bending (task 2), I felt like I judged my knuckles as closer to my wrist* and the reduction of the bias between *Intervention 1* and *Intervention 2* was not significant: $r(19) = 0.41$, $p = 0.073$. There was also a significant correlation between Q1*: Looking at my fingers spreading (task 1), I was surprised by where my knuckles were*, and the reduction of the bias after *Intervention 1*: $r(19) = 0.55$, $p = 0.012$.

The results of Experiment 4 showed that visual exposure to the participant's own hand in movement can reduce but not eliminate distal biases, replicating findings from Experiment 3. Furthermore, the results of this experiment showed that, contrary to my expectations, the reduction of the bias was not specific to the movement performed during the intervention, i.e. the bias was also reduced by a movement which did not involve bending the fingers to attract attention to the knuckles and make their location apparent.

7. 6. General discussion

The experiments described in this chapter followed up on research by Longo (2015) and Margolis & Longo, 2015. In Experiments 1 and 2, I found clear mislocalizations of the knuckles, of generally similar magnitude across conditions. The results of Experiment 1 showed that people misjudge the location of the knuckles whether they are asked to make the judgment using both vision and touch, or vision and touch separately. These results indicate that neither vision nor touch is necessary to elicit these biases. Moreover, the results of Experiment 2 showed that responses do not appear to be influenced by visual cues such as the

creases at the base of the fingers on the palm. In both experiments, biases in all conditions were strongly correlated. In Experiment 3 and 4, I investigated whether distal biases can be eliminated by careful inspection of participant's own hand in movement. In Experiment 3, the movement involved bending the fingers in a way which attracted attention to the knuckles and made their location apparent. In Experiment 4, a control condition was added with a different movement in which the knuckle joints were not involved in an obvious way. In both experiments, after the interventions participants judged their knuckles to be closer to the actual location, however, significant distal bias still remained. Interestingly, the results showed that participants had insight into the direction of the change, i.e. bias reduction. These results showed that the distal bias can be reduced but not completely eliminated by inspection of participant's own hand in movement. The reduction of the bias did not depend on the type of movement performed during the inspection of the hand.

My findings suggest that distal biases arise from a common, modality-independent cause. These results show that the distal bias is resistant to changes in the stimulus information and does not rely on any specific stimulus cue or even single sensory modality, suggesting that such mislocalisations reflect a conceptual misrepresentation of hand structure. Furthermore, I showed that distal biases can be reduced by careful inspection of participant's own hand in movement which suggests that participants updated their conceptual representation of the hand.

Most previous studies of the body structural description have been in the context of patients with autotopagnosia (e.g., Ogden, 1985; Sirigu et al., 1991; Buxbaum & Coslett, 2001) or finger agnosia (e.g., Kinsbourne & Warrington, 1962; Anema et al., 2011). Several recent studies, however, have investigated the body structural description in healthy people (e.g., Corradi-Dell'Acqua et al., 2008; Corradi-Dell'Acqua, Tomasino, & Fink, 2009; Rusconi et al., 2009, 2014; Tamè et al., 2017). In each of these studies, however, the focus has been on identifying its neural bases (e.g., Di Vita, Boccia, Palmero, & Guariglia, 2016), rather than revealing its representational content. My results suggest that there may be interesting deviations from actual body structure in the normal body structural description. Importantly,

however, I am not suggesting that the participants in my experiments showed evidence of a mild form of autotopagnosia. It is not the case that the participants were unable to perform the task or gave judgments which were random or disorganized. On the contrary, localization judgments were precise and highly structured. Yet these judgments were also systematically distorted, in a highly consistent and stereotyped way across people. Psychiatry differentiates between positive and negative symptoms, a distinction historically attributed to Jackson (Jackson, 1881). Negative symptoms are characterized by a deficit or loss of a cognitive function (like inability to localize body parts in autotopagnosia), whereas positive symptoms are abnormal by their very presence (like hallucinations or delusions). Adopting this framework, I could say that the results presented here showed not a negative symptom, since participants were able to perform the task and give coherent answers, but a positive symptom in the presence of distorted structural representation of the hand. Understanding the nature, extent, and functional role of these distortions is an important goal for future research.

The distal biases discussed in this chapter contribute to a growing literature showing that far from being a sure sign of pathology, distorted body representations are a normal part of healthy cognitive life (see Longo, 2017 for a review). As discussed in Chapter 1, previous studies have revealed large and stereotyped distortions underlying perceptual abilities including position sense (e.g., Longo & Haggard, 2010, 2012; Lopez, Schreyer, Preuss, & Mast, 2012; Ferrè, Vagnoni, & Haggard, 2013), tactile distance perception (e.g., Taylor-Clarke, Jacobsen, & Haggard, 2004; Anema, Wolswijk, Ruis, & Dijkerman, 2008; Longo & Haggard, 2011), localization of somatosensory stimuli (e.g. Mancini, Longo, Iannetti, & Haggard, 2011; Medina, Tamè, & Longo, 2017), and more abstract processes such as the conscious body image (e.g., Longo & Haggard, 2012; Fuentes, Longo, & Haggard, 2013; Linkenauger et al., 2015). The present results showing distal mislocalization of the knuckles fit within this general pattern and have interesting potential connections to other distortions. For example, the fact that people think their knuckles are farther forward in their hand than they actually are provides a potential explanation for the underestimation of finger length seen in body representations underlying position sense (Longo & Haggard, 2010; Saulton, Bülthoff

and de la Rosa, 2017). Furthermore, a study by Longo, Mattioni and Ganea (2015) found that the magnitude of knuckle mislocalization correlated across participants with underestimation of finger length in a proprioceptive localization task, but not with explicit judgments of finger length where participants compared the perceived size of parts of their finger with a line visually presented on a monitor.

Our hands are an ever-present part of our perceptual experience starting from early childhood (Fausey et al., 2016), and an important source of information about the world. It may thus seem odd, or even incredible, that our knowledge of their structure is so systematically distorted. This is especially true since joints, such as the knuckles, are frequently taken to be especially critical for providing spatial structure to the body (Bermúdez, 1998), reference points for touch (Weber, 1834/1996; Boring, 1942; Cholewiak & Collins, 2003), and boundaries for categorical perception on the body (de Vignemont, Majid, Jola, & Haggard, 2009; Le Cornu Knight, Longo, & Bremner, 2014). Hand shapes inform perceivers about the properties of objects (Gibson, 1962; Klatzky et al., 1989) and prioritize spatial attention (Reed, Grubb, & Steele, 2006). It may be that hands direct attention to objects rather than to themselves. As the Chinese proverb goes, "When the finger is pointing at the sky, only the fool looks at the finger."

The experiments discussed in this chapter are not directly related to the main topic of my thesis and are mostly built on different literature. However, upon closer inspection, there are several common points between these two lines of research. Both deal with bodily distortions, malleability of the representations of body parts, specifically hands. The results presented here show that the mental representation of the body part as familiar as the hand can be systematically distorted. This is consistent with the hypothesis that the size of one's own body can be misrepresented. Furthermore, both lines of research look at the way in which visual experience with bodies affects these distortions and involve a discussion on perceptual vs conceptual bias. The difference is, that the distal bias presented in this chapter does not rely on visual or other sensory cues and is only partially reduced after visual inspection of the hand, whereas body size aftereffects arise from visual exposure to bodies. Therefore, I explain the

distal bias as a conceptual distortion related to conceptual mislocalisation of the knuckles, while I interpret the adaptation aftereffects as a perceptual bias.

Chapter 8: General discussion

8.1 Summary of the main findings.

In previous chapters, I described the body of work I conducted during my doctoral studies. In my project, I investigated how visual exposure to bodies, especially looking at other people, influences representations of our body. I was particularly interested in body image, i.e. the way we consciously perceive ourselves. Body image includes both the emotional-cognitive component, i.e. attitudes towards our body, and the perceptual component, i.e. "the picture of our own body which we form in our mind" (Schilder, 1935/1950). It has been previously shown that exposure to thin, idealized images changes attitudes towards one's own body (Groesz, Levine, & Murnen, 2002; Tiggemann & McGill, 2004) but can exposure to certain body types change the way we actually *perceive* ourselves? Recently, several authors suggested that indeed exposure to extreme body types, such as 'size zero' models which are ever-present in media, can influence the way we actually *see* our own bodies and proposed visual adaptation as one of the mechanisms that may be involved in this process (Hummel, Rudolf, Untch, Grabhorn & Mohr, 2012b; Brooks, Mond, Stevenson & Stephen, 2016; Challinor, Mond, Stephen, Mitchison, Hay & Brooks 2017). Thus, the main subject of my thesis deals with the question whether short-term effects of adaptation can constitute an experimental model for the long-term effects of media influences on body image.

I started with investigating whether exposure to extreme, i.e. very thin or very fat, bodies affects representations of one's own body and other bodies in a similar way. Previous research showed clear evidence that body size adaptation affects perception of bodies. The question that has not previously been answered is how similar body size aftereffects are for one's own body (i.e., the body image) and for bodies in general, in other words, does exposure to bodies affect judgements about our own body in a self-specific way, or is the effect generic to all bodies. For visual adaptation to constitute an experimental model of media effect on body image distortions, some degree of self-specificity should be expected, i.e. the effect that

adaptation has on one's own body should also differ from the general effect of adaptation on all images of bodies. If adaptation affects all bodies equally, the relative difference between one's own body and other bodies should not change, i.e. both our own bodies and bodies presented in media should be affected by adaptation. As a consequence, our own body should not appear to us as fatter in comparison to other bodies. In a series of experiments discussed in Chapter 2, I tested whether adaptation to a thin or a fat body affected judgements about the participant's own body (Experiments 1-3), an average body (Experiment 1) or the body of another person (Experiments 2-3). I found virtually identical aftereffects in all conditions suggesting that body size adaptation affects representations of one's own body and other bodies in a similar way. One possible interpretation of this finding is that visual adaptation affects perception of immediately presented visual stimuli but not the body image. A study described in Chapter 3 further investigated whether adaptation affects stored representation of one's body. I used a method in which participant's body image can be measured implicitly - the Body Image Task (Fuentes et al., 2013). I found no effect of adaptation in the BIT providing no evidence for the effect of visual adaptation on stored representations.

In media, we are often presented with bodies that are only partially visible, e.g. profile pictures and partial body photographs in magazines. Adaptation studies, on the other hand, have mostly used images of whole bodies as adaptors. Thus, another interesting question is whether exposure to a whole body is necessary for adaptation to occur or whether images of body parts are enough to induce body size aftereffects. I conducted a series of experiments which tested whether adaptation to extreme body types can transfer between whole bodies and body parts such as faces and hands. In Chapter 4, I described my finding showing that visual adaptation to facial adiposity induces negative aftereffects, similar to those reported in body adaptation studies. This effect has not been demonstrated previously and here it served as a preliminary finding for a series of experiments investigating transfer of adiposity aftereffects between full body images and body parts presented in Chapter 5. The results from these experiments suggest that observers do not need to be exposed to the full body images to

experience body size aftereffects. While faces and hands may not be the body parts most typically associated with the concept of fatness or thinness, they are the body parts of other people to which we are most often exposed to, since they are least likely to be covered by clothes. My findings suggest that even these body parts can serve as adiposity cues and induce body size adaptation, adding to the existing literature reporting cross-category aftereffects transfer between stimuli that have different low level properties but are linked on the abstract level (Ghuman et al., 2010; Palumbo et al. 2015; Javadi & Wee, 2012; Greene & Oliva, 2010).

The results of the cross-category adaptation studies raise the question of the overlap between the adapting and test stimuli that is necessary for adaptation to occur. As a next step in my project, in two experiments (described in Chapter 6) I explored the transfer of body size aftereffects between different modalities: vision and passive touch (Experiment 1) and between vision and haptics (Experiment 2). In Experiment 1, I investigated whether visual adaptation to a narrow or a wide hand of another person affects participants' perception of tactile distances on the hand. I found no evidence of cross-modal adaptation, suggesting that visual adaptation to other bodies does not affect the model of body size and shape mediating the perception of touch on the skin. In Experiment 2, I asked whether adaptation to a haptically explored body produces aftereffects in visual perception of other bodies. The results showed transfer of aftereffect in the thin condition but not in the fat condition, suggesting that adiposity cues in a different modality (active touch) can induce aftereffects in visual perception of bodies.

My results showed no evidence that short-term adaptation to other bodies affects the representation of one's own body, i.e. the body image, in a self-specific way. The results do suggest, however, that body size adaptation affects higher-level general representations of bodies as shown by cross-category transfer and some preliminary evidence for the transfer of aftereffects between vision and haptics.

In my second line of research, described in Chapter 7, I followed up on studies by Longo (2015) and Margolis & Longo, 2015 reporting distal biases in the localization of the knuckles. I first investigated whether the magnitude of distal bias may depend on the

perceptual information available for response. In Experiment 1, I found that participants misjudged the location of the knuckles whether they were asked to make the judgment using both vision and touch, or vision and touch separately. These results indicate that neither vision nor touch is necessary to elicit these biases. Moreover, Experiment 2 showed that responses do not appear to be influenced by visual cues such as the creases at the base of the fingers on the palm.

Further, in Experiment 3 and 4, I asked whether distorted representation of the hand (i.e. distal biases) can be affected by careful inspection of the participant's own hand in movement. In Experiment 3, the movement involved bending the fingers which attracted attention to the knuckles and made their location apparent. In Experiment 4, I added a control condition with a different movement in which the knuckle joints were not involved in an obvious way. In both experiments, after the interventions participants judged their knuckles to be closer to their actual location, however, significant distal bias still remained. Interestingly, the results showed that participants had insight into the direction of the change. These results showed that the distal bias can be reduced but not eliminated by inspection of the participant's own hand in movement. Furthermore, the reduction of the bias did not depend on the type of movement performed during the inspection of the hand.

Taken together, my findings show that distal bias is resistant to changes in the stimulus information and does not rely on any specific stimulus cue or even single sensory modality, suggesting that such mislocalisations reflect a conceptual misrepresentation of hand structure. Furthermore, I showed that distal biases can be reduced by careful inspection of the participant's own hand in movement which suggests that participants updated their conceptual representation of the hand.

8.2 The origin of high-level adaptation aftereffects

In Chapter 1, I discussed a growing body of research on "high-level" adaptation aftereffects for complex stimuli such as faces, bodies and actions. The results of my studies described in Chapters 2-6 add to this existing literature, not only replicating previous findings

from body size adaptation, but also showing adiposity aftereffects in face adaptation and, most importantly, transfer of adiposity aftereffects between the whole bodies and body parts such as faces and hands. These results, particularly the cross-category transfer, suggest that adaptation operates on higher levels of representations. However, the nature of higher-level adaptation remains a matter of debate and evokes some controversies with researchers debating whether these high-level aftereffects results from changes to high level-representations or whether they are "inherited" from low-level stages of processing (e.g. Webster & MacLin, 1999; Fox & Burton, 2007; Xu, Dayan, Lipkin & Qian, 2008; Webster & MacLeod, 2011; Xu, Liu, Dayan & Qian, 2012). Other researchers question whether these effects are perceptual in nature and suggest instead a cognitive origin, e.g. decision bias (Storrs, 2015).

Thus, the results from my experiments can also be interpreted in the context of the debate of the origins of higher level adaptation aftereffects. This question is interesting not only from the point of view of a vision researcher but also in the light of the main question of my thesis in which I ask whether body size adaptation affects body representations. In order to correctly interpret aftereffects and use adaptation as a tool for studying representations, it is essential to know how adaptation works. If body size adaptation happens at low-level of visual processing it seems unlikely that it can result in specific, long lasting changes to body representations.

High-level aftereffects as a passive reflection of low-level adaptation

When we look at a body we perceive features such as gender, attractiveness, its adiposity level which is most often referred to as "body size", as well as many other of its high-level characteristics. However, we also perceive its angular size, e.g. the space it occupies in our visual field, and other low-level features such as curvature of lines that define its shape. It is still not well established which features contribute to the aftereffects measured in body adaptation experiments. When used as adaptors, complex stimuli can produce both high and low level aftereffects. For example, a smiling face may induce aftereffects in perceived facial

expression (high level) but also in perceived curvature of the lips (low level). In such cases, it is unclear whether high level aftereffects are caused by mechanisms operating in higher level areas and reflect direct changes in face representations, or whether they originate in low-level areas processing simple features.

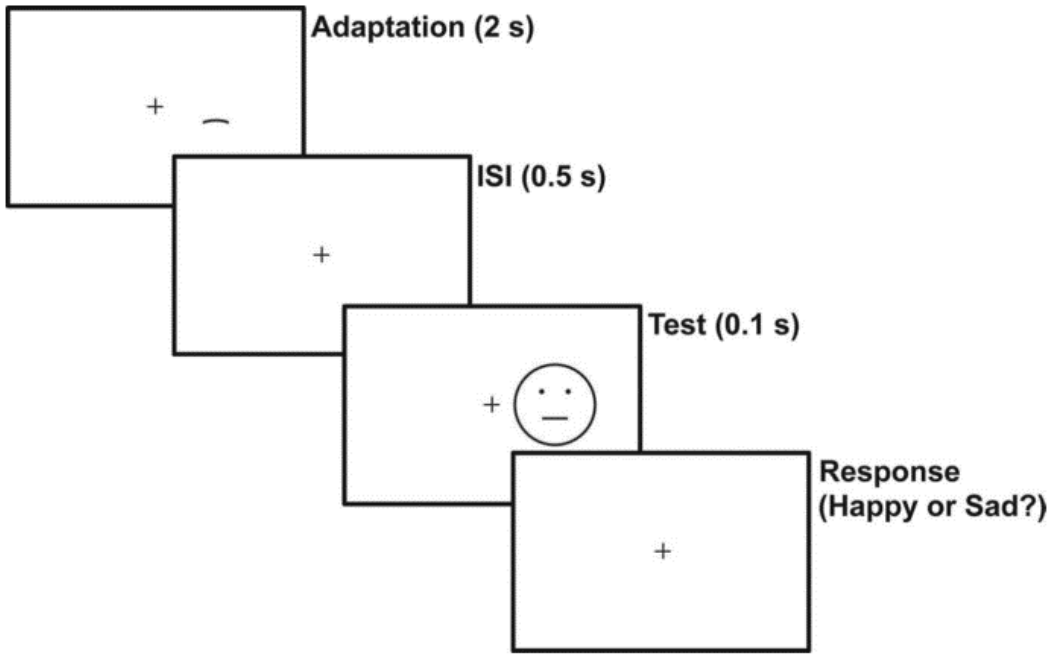

Figure 8.1: Adaptation to curvature and emotional expression. A study by Xu at al. (2008) showed that adaptation to a curved line, affected perception of a facial expression in a cartoon face. Smaller but still significant results were found with a photograph of an actual face used as a test stimuli. Image source: Xu, Dayan, Lipkin and Qian (2008, p. 3376).

Studies on adaptation to faces showed that aftereffects can transfer between images that vary in their low level properties. For example, Fox and Burton (2007) reported that two different images of the same person displaying a particular emotional expression produced equally robust aftereffects. Furthermore, similar results were found with faces of different identity or gender suggesting that adaptation was not based on low-level image properties. Similarly, body size aftereffects were shown to transfer between bodies of different identity (Hummel et al. 2012b; Brooks et al., 2016). These results are generally interpreted as an

indication that high-level aftereffects do not depend solely on low-level adaptation. However, it can still be argued that low-level adaptation to simple geometric properties of the presented bodies, which were shared between the identities, played a role in these results. Xu et al. (2008) showed that curve adaptation produced not only a curvature aftereffect but also biased perception of a facial-expression in a cartoon face (Figure 8.1). The authors also found smaller but still significant results using a photograph of an actual face as a test stimuli, suggesting that local, low-level features do indeed contribute to face adaptation.

Thus, one possible interpretation of body size adaptation could be that body size adaptation aftereffects result from adaptation to the low level features of the stimuli: the overall size or a specific dimension such as the width. Hummel et al. (2012a) tested this question using wide and narrow rectangles as adaptors and found no significant aftereffects in perception of test bodies, which suggests that the effects found in body size adaptation studies are not based solely on adaptation to low-level features and simple geometric properties of the presented bodies. One objection which can be raised here is that rectangles are very simple objects and as such may not be similar enough, in terms of their low-level features, to induce aftereffects in body perception. It is possible that more complex shapes which are more similar to bodies, e.g. bottles or a guitars, could evoke aftereffects in body perception.

My research did not directly investigate the issue whether high-level aftereffects can be dissociated from low-level adaptation: the stimuli in my experiments were not designed to answer this specific question. The aftereffects of both cross-category and cross-modal adaptation reported here are notably smaller than the aftereffects in body to body adaptation studies. This may suggest that although adaptation relies in part on the low-level similarity between the test and the adaptor. However, although smaller the aftereffects were still present suggesting that body size adaptation does not rely only on low-level features.

Furthermore, a closer look at the dimensions of the stimuli used in cross-category experiments reported in Chapter 5, suggests that low-level adaptation could not explain the results. The height of all stimuli used in these experiments was kept constant (18 cm, 20° visual angle) but the width was not. In Experiment 3, the width of both thin and fat body adaptors

was smaller than that of the test faces. Therefore, if participants were adapted to the low-level features such as the width of the adaptors, adaptation should bias perception in the same direction in both conditions. However, the results from this experiment showed aftereffects going in the opposite directions in the two conditions. Thus, it seems unlikely that aftereffects occurred simply due to low-level adaptation to the dimensions of the stimuli such as the width. The stimuli in my studies were more complex than simple rectangles used by Hummel et al. (2012a) but the shape similarity between the test and the adaptor was not controlled for. A future experiment with stimuli properly controlled for their low-level features should answer the question of the origins of the body size aftereffects more definitely.

High-level aftereffects as a cognitive bias

High-level adaptation, especially transfer of aftereffects between stimuli belonging to different global categories, may also be interpreted in terms of adaptation to a more general, abstract concept rather than a higher level visual representation. Previous studies on cross-category gender adaptation between bodies and gender-specific objects showed mixed results. Ghuman et al. (2010) found no transfer of gender aftereffects between faces and gender-specific objects e.g. shoes, while Javadi & Wee (2012) reported opposite results. A question whether body size aftereffects can be induced with adaptation to objects related to an abstract concept of adiposity has not yet been studied. Perhaps, this is because it may be difficult to find non-body objects which are unambiguously associated with only one end of the thin-fat spectrum, e.g. an image of a bathroom scale can be conceptually linked to both underweight and overweight body.

Javadi & Wee (2012) interpret they cross-category transfer between faces and objects in terms of neural adaptation of individual neurons tuned for gender which have been identified in previous studies (Sergent, Ohta, & McDonald, 1992; Kaul, Rees & Ishai, 2011). However, it remains a controversial issue whether high-level aftereffects are truly a result of adaptation and not another process, e.g. related to participants strategy during the task, that could affect the response and is not perceptual in origin, such as decision bias (Storrs, 2015) For instance,

participants may consciously or unconsciously use a rule: “if in doubt, say the test was different from the adaptor”. Further, Storrs (2015) observes that most adaptation studies uses a categorization task in which “the placement of the category boundary is determined both by the participant’s sensory evidence and by her criteria for applying each of the response labels to that evidence” (Storrs, 2015, p.2). One method from distinguishing a perceptual from a cognitive bias would be to use, instead of a categorization task, a method of adjustment task with a test stimulus presented in an adapted location of the visual field and a reference stimulus in a unadopted location. This method, however is not suited for many higher-level aftereffects as they often do not depend on a retinal location. Furthermore, this method is not applicable to cross-category adaptation experiments where it is not possible to perceptually match the adaptor and the test.

Another way of distinguishing between an adaptation aftereffect and a result of a cognitive strategy is to vary the length of exposure to the adapting stimulus. One of the main characteristics of perceptual aftereffects is that their magnitude depends on the length of adaptation (Gibson & Radner, 1937; Hershenson, 1993), whereas cognitive strategy, such as the one described above, seems unlikely to be affected by it. Indeed, the relationship between the duration of the adaptation period and the magnitude of the aftereffects has already been reported for higher-level aftereffects. For example, Leopold, Rhodes, Mueller & Jeffery (2005) and Rhodes, Jeffery, Clifford & Leopold (2007) showed that facial identity adaptation aftereffect grows logarithmically stronger as a function of adaptation time. Furthermore, in the study by Ghuman et al. (2010) the magnitude of the gender aftereffect in perception of faces increased logarithmically with the length of the exposure to the female or male body adaptor which suggests the perceptual origin of the aftereffects even in cross-category adaptation.

Previous studies showed that the magnitude of both low and high level aftereffects increases not only with the length of adaptation but also with extremity of the adaptor (McKone, Jeffery, Boeing, Clifford, & Rhodes, 2014). Therefore using bodies that differ in adiposity (e.g. thinner than average and extremely thin) as adaptors in future research would

allow to draw better conclusions about the results, i.e. interpret them as a perceptual rather than cognitive bias.

8.3 Adaptation and task parameters

Time

It has been shown that both the magnitude and the duration of adaptation aftereffects depends on the length of exposure to the adaptor (Herschensohn, 1993; Leopold et al., 2005; Rhodes et al., 2007). Therefore, long-lasting aftereffects require prolonged exposure which can be difficult to induce experimentally. However, researchers studying adaptation have proposed that many long-term biases can be seen as aftereffects of naturally occurring adaptation to stimuli in our everyday environment (Clifford & Rhodes, 2005). For example, people show enhanced detection and discrimination of vertical and horizontal lines (cardinal orientations) compared with tilted lines (oblique orientations): small deviations from a horizontal line are detected much easier than same difference between tilted lines (Appelle, 1972). This bias, known as "the oblique effect", is believed to be a result of natural adaptation to the environment in which vertical and horizontal lines are statistically the most frequent (Dragoi, Turcu, & Sur, 2001). Another example comes from face perception. Webster et al. (2004) created a series of morphs between Caucasian and Asian faces and then asked their participants to categorize these faces by their ethnicity to estimate the most neutral face, i.e. the face that was equally likely to be judged as Caucasian or Asian. The results showed that this neutral face was different for Caucasian and Asian participants: in each group the neutral face was closer to participants' own ethnicity. This finding, consistent with typical direction of adaptation shifting perceived norm towards the adaptor, can be explained in terms of long-term aftereffects resulting from life-long exposure to faces from own ethnic group. Interestingly, the same study also compared the results of Asian participants who just arrived in the United States with those who lived in the US for a year or longer and showed that the neutral face in the latter group was shifted towards the Caucasian face, indicating that

increased exposure to Caucasian faces after changing the country of residence affected facial norms in Asian participants. Therefore, this example not only shows long-term perceptual biases that are formed over many years (life-time exposure) but also suggests that these biases can itself be adapted as a result of a change in the environment.

The biases described above are examples of naturally occurring adaptation. Adaptation aftereffects induced experimentally in the lab are usually short lasting, as the exposure time in the lab also tends to be short. Some examples of long-term adaptation aftereffects come from studies on low-level adaptation aftereffects. For example, Neitz, Carroll, Yamauchi, Neitz and Williams (2002) induced colour adaptation using colour-filtered goggles and dyed contact lenses. The exposure lasted 4, 8, or 12 hours at a time, resulting in aftereffects lasting up to 7 days. Other notable examples come from prism adaptation in which participants wear special goggles, which shift visual field to the left or to the right, while performing a visuomotor task in which they need to reach a visual target in front of them. The effect of prism adaptation is tested on the same visuomotor task but without distorting goggles and measured as a reaching error. Hatada, Miall and Rossetti (2006) reported proprioceptive aftereffects (reaching errors) that lasted 7 days after prism adaptation training of 75 minutes. Studies on prism adaptation in monkeys showed effects that lasted 3 days after 30 minutes of training (Yin & Kitazawa, 2001).

To the best of my knowledge, there are currently no studies that have looked at body adaptation aftereffects induced experimentally over a period longer than several minutes. Previous studies which reported body aftereffects (Glauert et al., 2009; Hummel et al., 2012a; Hummel et al., 2012b) used initial adaptation between 1 and 4 minutes and top up adaptation of 5 to 7.5 seconds. The experiments discussed in this thesis investigated short term effects of relatively short adaptation period (1-2 minutes of initial exposure and additional 3-6 seconds of top up adaptation). The parameters in my experiments were based on previous studies but also dictated by the practical issues such as the overall duration of the experiment. It is possible that longer adaptation would produce long-term aftereffects. One way of addressing this question would be by using virtual reality to create environment, populated with characters of

specific body type, in which participants could spend extended amount of time without getting tired or loosing attention. Future studies should investigate whether that kind of prolonged exposure would result in long lasting aftereffects.

As discussed in the previous section, studies on both low-level and high-level perceptual aftereffects showed that their magnitude depends on the length of adaptation (Gibson & Radner, 1937; Hershenson, 1993; Leopold et al., 2005; Rhodes et al. 2007; Ghuman et al. 2010). This particular characteristic of adaptation aftereffects also raises an interesting question whether longer adaptation duration can evoke aftereffects which are not only stronger and longer lasting but also qualitatively different e.g. affecting perception in a different modality. However, so far there is little evidence that longer adaptation can cause a qualitative change in the nature of the aftereffects. A study by Cuturi and MacNeilage (2014) found cross-modal transfer of motion aftereffects only in the longest adaptation condition, suggesting that the length of the adaptation can produce qualitatively different aftereffects. It remains an open question whether longer adaptation would affect body representations in a way that goes beyond visual perception. Future studies should examine whether varying the length of exposure can affect body size adaptation, especially aftereffects in another modality, related to body representation, e.g. touch.

Attention

Another aspect of the experimental design that can affect adaptation aftereffects is the attention. Attention has been shown to enhance adaptation to low-level features (Rezec, Krekelberg and Dobkins, 2004; Pestilli, Viera & Carrasco, 2007) and previous research suggests that attention may also amplify the higher level aftereffects in face adaptation (Rhodes, Jeffery, Evangelista, Ewing, Peters & Taylor, 2011) and in cross-category adaptation between faces and objects (Javadi & Wee, 2012). On the other hand, some studies reported that low-level adaptation does not require attention (Wohlgemuth, 1911; Morgan, 2011).

In my experiments, I did not control for the effect of attention. During adaptation, participants passively view the images with head and eye movements unrestricted. The

adapting image flickered with a low frequency to capture participants' attention. Otherwise, my experiments did not measure or manipulate the attention during adaptation period.

In the first cross-category experiment, described in Chapter 5, I did not find significant transfer of adiposity aftereffects between faces and bodies. I hypothesized that these results were caused by the adapting stimuli which did not attract enough attention to induce strong adaptation. The faces used as adaptors in this experiment were looking away from the observer. It has been shown that people have a robust preference for direct rather than averted gaze (Lawson, 2015). Indeed, when I used different faces (i.e. looking straight) as adaptors, I obtained different results. Of course, it is not possible to make conclusions based on this observation. However, it does inspire the question whether attention to adapting stimuli is necessary for adaptation to occur.

Stephen, Sturman, Stevenson, Mond and Brooks (2018) showed that attention mediates the relationship between body satisfaction and susceptibility to the body size adaptation effect, i.e. participants with low body satisfaction looked at images of thin bodies more which lead to stronger adaptation aftereffect. The effect of covert attention on body size adaptation has not been demonstrated. Interestingly, it has been shown that passive viewing of thin bodies, during a cognitively engaging task, does not have detrimental effect on mood and body satisfaction (Want & Saiphoo, 2017) suggesting that social comparisons are cognitively inefficient and require attention. It would be interesting to further investigate how attention affects body size adaptation to answer the question whether mere exposure to media images is enough for body size aftereffects to occur or whether observers need to pay attention.

8.4 Underlying mechanisms

In the general introduction in Chapter 1, I described possible models explaining neural mechanisms of adaption, such as shifts in tuning curves of neurons, normalization and predictive coding. Most of the neurophysiological data on which these models are based comes from low-level aftereffects and it is not well-studied how these mechanism could translate to high-level adaptation. However, some attempts have been made to unify the adaptation

framework to encompass both high and low level aftereffects. For example, Zhao, Seriès, Hancock & Bednar (2011) proposed a computational model that explains both orientation aftereffects (low-level) and facial gender aftereffects (high-level) suggesting that similar neural mechanisms may be involved in both. In this model, neurons in higher areas are tuned to exemplar faces just like neurons in lower areas are tuned to orientation of lines (see Chapter 1, p. 22 for explanation of orientation tuning). This means that each neuron responds selectively to a specific range of faces, i.e. each neuron has a different "preferred" exemplar face. These preferred exemplar faces are distributed across the entire spectrum of faces. Adaptation reduces the responses of neurons tuned to the adaptor which causes other faces to appear more prominent and biased away from the adaptor. This account of adaptation is called an "exemplar-based model".

An alternative explanation is offered by a "norm-based" model, also called "opponent coding" in which faces are coded with respect to the norm, i.e. the average face (Rhodes & Jeffery, 2006; Pond, Kloth, McKone, Jeffery, Irons & Rhodes, 2013). In this model, neurons form two opponent channels each broadly tuned to one side of the spectrum, e.g. male vs female faces. The average or neutral face results in equally weak activation in both channels. According to this model, adaptation reduces responses in the channel that is tuned to the adapting feature and biases perception of all faces in the same direction. In consequence, the average is shifted towards the adaptor. This model has been used to explain adaptation to facial features such as identity (Rhodes & Jeffery, 2006) and age (O'Neil, Mac, Rhodes & Webster, 2014) but also lower-level features such as colour (Webster & Leonard, 2008). Importantly, norm-based model has also been proposed for adaptation to identity of bodies (Rhodes, Jeffery, Boeing & Calder, 2013).

It has not yet been directly tested whether body size is processed according to exemplar or opponent coding. One possible way of distinguishing between these two models is to use test bodies of more extreme adiposity than the adaptors, as the two models have different predictions in this case. In both models, after adaptation to a thin body an average body will appear fatter. However, according to the exemplar based model, the test stimuli will

always appear biased away from the adaptor and therefore, a body that is already thinner than the thin adaptor will now appear even thinner. The opposite is true in the norm-based model where all bodies will be biased in the same direction, so even a body thinner than the thin adaptor will appear fatter after adaptation.

In my experiments, I did not test the effect of adaptation on stimuli that are more extreme that the adaptors and thus it remains an open question for future research. I also did not vary the extremity of the adaptors using only extreme body types. However, the results of previous research (Glauert et al., 2009) suggest that, like in face adaptation (McKone, Jeffery, Boeing, Clifford, & Rhodes, 2014) the magnitude of body size aftereffect increases with extremity of the adaptor which would also be predicted by norm-based but not exemplar-based coding. If the norm-based model is correct, neurons in higher-level areas representing bodies, such as the extrastriate body area (Downing, Jiang, Shuman & Kanwisher, 2001), are pooled in two channels tuned to thin and fat bodies. In this model, the adiposity of each body is represented by the ratio of activation of these two channels and the norm, i.e. the average body equally deactivates both channels. Body size adaptation aftereffects arise from a temporary shift of this norm.

Another question is how these short-term shifts give rise to long-term perceptual biases. Since the mechanism of adaptation are not well established, we can only speculate on how over different time-scales. One possibility is that the long term bias results from the same mechanisms operating over different time-frame. Which means that constant exposure to adapting stimuli permanently recalibrates the norm.

In my thesis, I was specifically interested in the visual component of body image and the way it can be influenced by perceptual aftereffects of body size adaptation. However, exposure to idealized bodies has also an effect on attitudes towards one's own body, as shown by previous studies (Groesz, Levine, & Murnen, 2002; Tiggemann & McGill, 2004). There is one obvious way in which these two are related such as that any change in the way we consciously perceive our body will lead to the corresponding change in the attitudes towards it. A person with biased visual perception of their own body size does not have accurate

information for cognitive assessment, e.g. may think she is overweight, while in fact she is not. Furthermore, adaptation recalibrates the bodily norm and affects what is considered the average body. This can also cause changes in attitudes as a result of comparisons, e.g. the person may think her body is much above the average size, while it is within the average range. Another way in which adaptation to idealized bodies can affect attitudes is by drawing attention towards extremely thin bodies and increasing comparisons to idealized bodies instead of average bodies. This last mechanism can be independent from perceptual aftereffects

8. 5 Limitations and future directions

As I discussed in the introduction, in all experiments presented in Chapters 2-6, I restricted my samples to female participants to be consistent with previous literature (e.g. Winkler & Rhodes, 2005; Glauert at al., 2009; Hummel et al., 2012, Brooks et al., 2016). Therefore, the question whether results presented here generalize to male population remains open. Although negative body image is a problem traditionally associated with women (Tiggemann & Rothblum, 1988; Muth & Cash, 1997), recent studies show that body image concerns in men increase as well (see Sklar, 2017 for a review). While women usually want to decrease their body size, men can aim to both decrease their body size (loose fat) as well as increase it (build muscles) (Labre, 2002). This could possible cause some theoretical problems in interpreting aftereffects if adaptation operated on a single dimension of body size. However, an interesting recent study by Sturman, Stephen, Mond, Stevenson and Brooks (2017) showed independent body size adaptation aftereffects of fat and muscles. After adaptation to a muscular body other bodies appeared less muscular but not thinner, while after adaptation to a fat body, other bodies appear thinner but not less muscular. Furthermore, the results of this study were similar for male and female participants who viewed images of their own gender, which suggest that men are affected by adaptation in a similar way as women. Future research should test whether the results presented here also generalize to male population.

Previous body adaptation studies often used body images that were stretched in width (e.g. Winkler & Rhodes, 2005; Hummel et al. 2012a, Hummel et al. 2012b). Compared to this

method, my stimuli which reflected veridical, biologically realistic changes were a change in the right direction. However, in the meantime, new methods has been developed that allow to scan participants own bodies and model biologically realistic changes of body size specific to individual bodies and therefore construct stimuli based on participants, e.g. the virtual caliper (Thaler, Piryankova, Stefanucci, Pujades, de la Rosa, Streuber, Romero, Black & Mohler, 2018). This opens new ways to differently address questions presented in my thesis. For example, it allows to design an experiment with self and other conditions, in which participant is matched with a body of the same BMI and shape but different identity. In this design, it would be possible to use the other body as both adaptor and test and see whether it induces the same aftereffects in participant's own body. Furthermore, it could be tested whether any difference found is specific to participant's own body or is it due to using bodies of two different identities. Another advantage of using participants body scans, comes from the fact that bodies differ not only in size but also in shape, body composition (fat vs muscles) and the way the fat is stored on the body. My stimuli reflected realistic body size changes but only in one specific body identity. Comparing own body to a body that is very different in shape and adiposity distribution to decide which one is thinner/fatter is, therefore, not an easy task. Using stimuli that reflect biologically realistic changes in body size that are also specific to the body of the participant can facilitate this task and lead to more accurate answers and in consequence provides more accurate measure of body image.

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